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(54) **MONITOR AND CONTROL SYSTEMS AND METHODS FOR OCCUPANT SAFETY AND ENERGY EFFICIENCY OF STRUCTURES**

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(52) **U.S. Cl.**

CPC ***H04N 5/33*** (2013.01); ***H04N 5/2257*** (2013.01); ***H04N 5/3658*** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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(57) **ABSTRACT**

Various systems and methods are disclosed for monitoring and controlling using small infrared imaging modules to enhance occupant safety and energy efficiency of buildings and structures. In one example, thermal images captured by infrared imaging modules may be analyzed to detect presence of persons, identify and classify power-consuming objects, and monitor environmental conditions. Based on the processed thermal images, various power-consuming objects (e.g., an HVAC system, lighting, a water heater, and other appliances) may be controlled to increase energy efficiency. In another example, thermal images captured by infrared imaging modules may be analyzed to detect various hazardous conditions, such as a combustible gas leak, a CO gas leak, a water leak, fire, smoke, and, an electrical hotspot.

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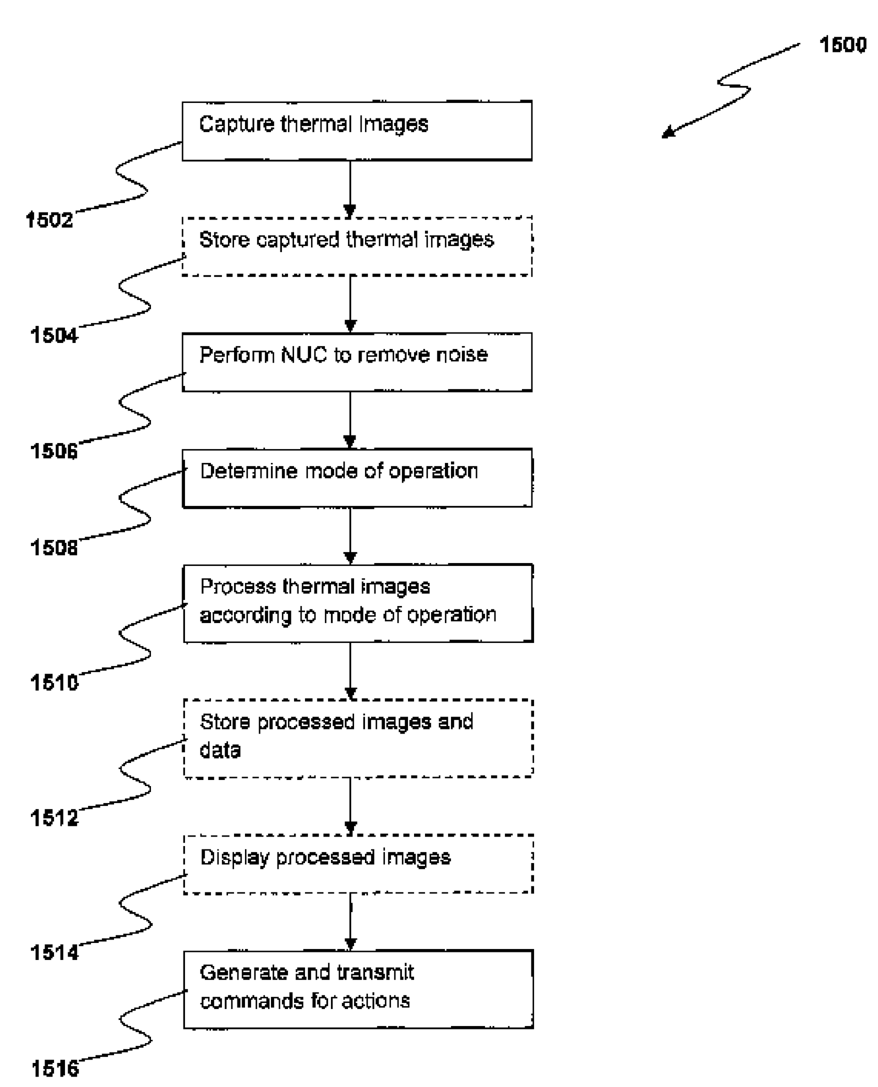

If such hazardous conditions are detected, an appropriate warning may be generated and/or various objects may be controlled to remedy the conditions.

20 Claims, 20 Drawing Sheets

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KR	2011019994	3/2011
KR	2011024290	3/2011
KR	101111167	4/2011
KR	1111167	2/2012
KR	1020130142810	12/2013
TW	201116030	5/2011
WO	WO 00/23814	4/2000
WO	WO 03/093963	11/2003
WO	WO 2005/002228	1/2005
WO	WO 2005/088846	9/2005
WO	WO 2006/112866	10/2006
WO	WO 2007/006242	1/2007
WO	WO 2009/122114	10/2009
WO	WO 2010/005152	1/2010
WO	WO 2010/033142	3/2010
WO	WO 2010/121354 A1	10/2010

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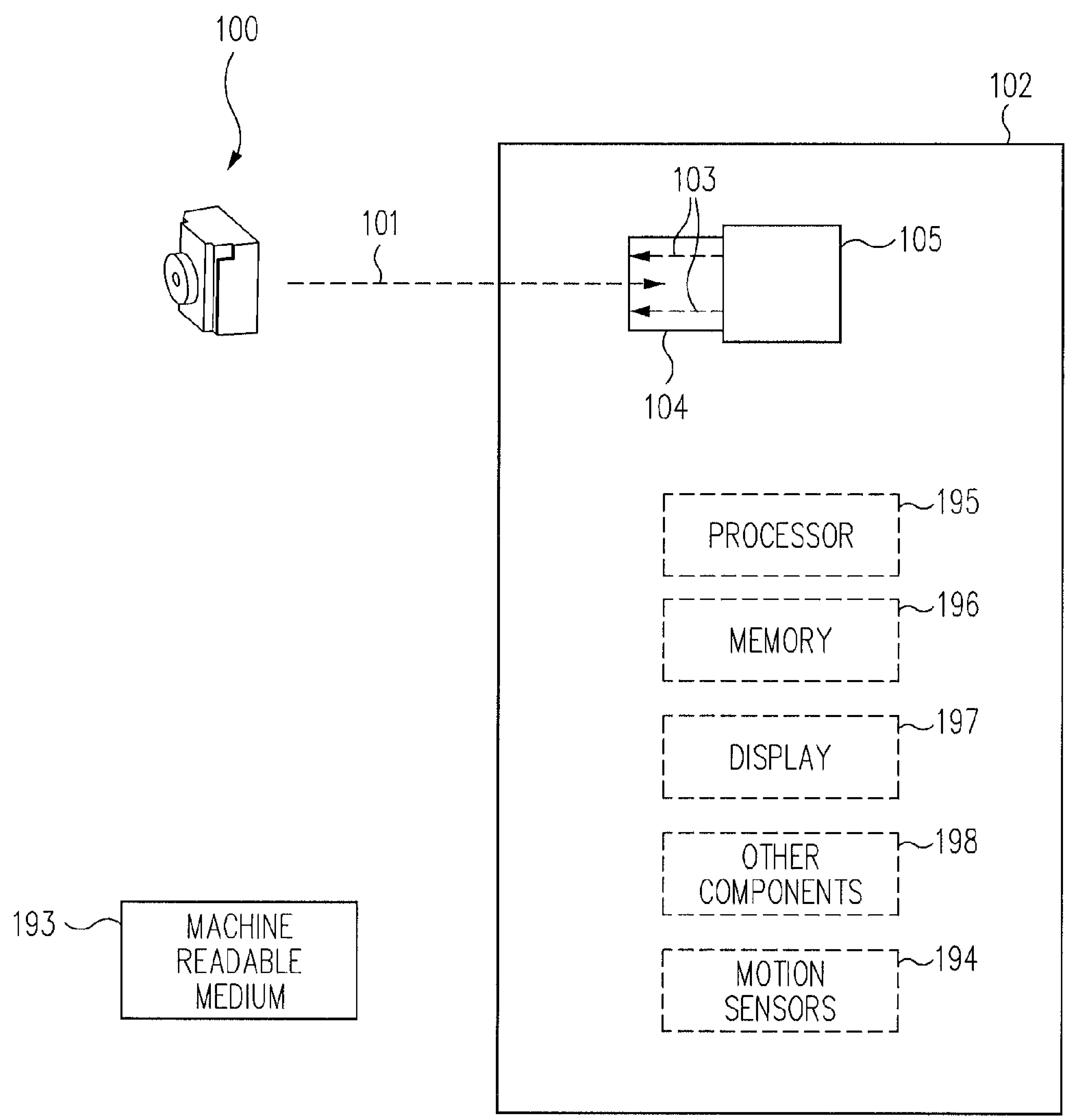

100
101
102
103
105
104
PROCESSOR
195
MEMORY
196
DISPLAY
197
OTHER COMPONENTS
198
MOTION SENSORS
194
193
MACHINE READABLE MEDIUM

FIG. 1

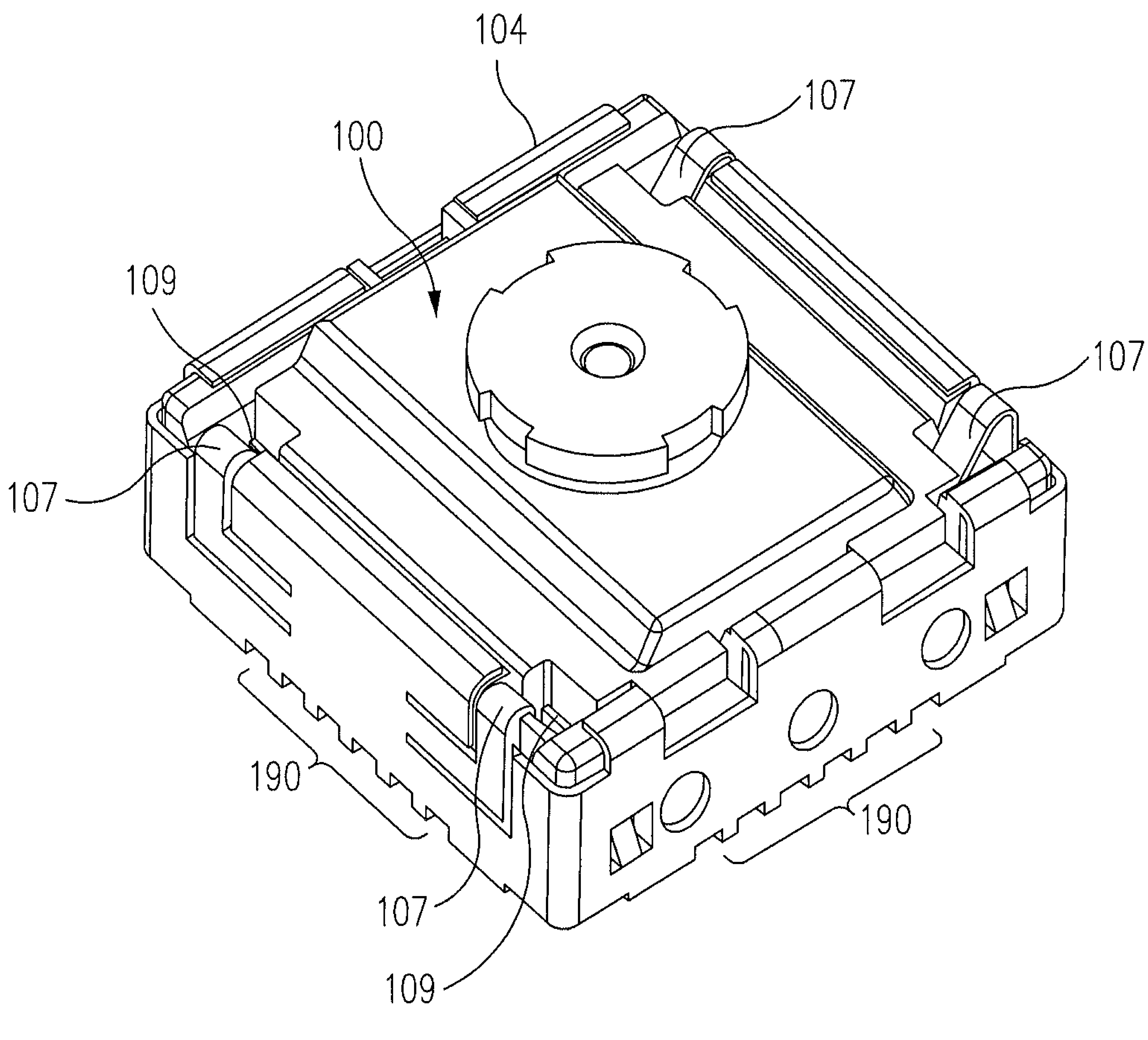


FIG. 2

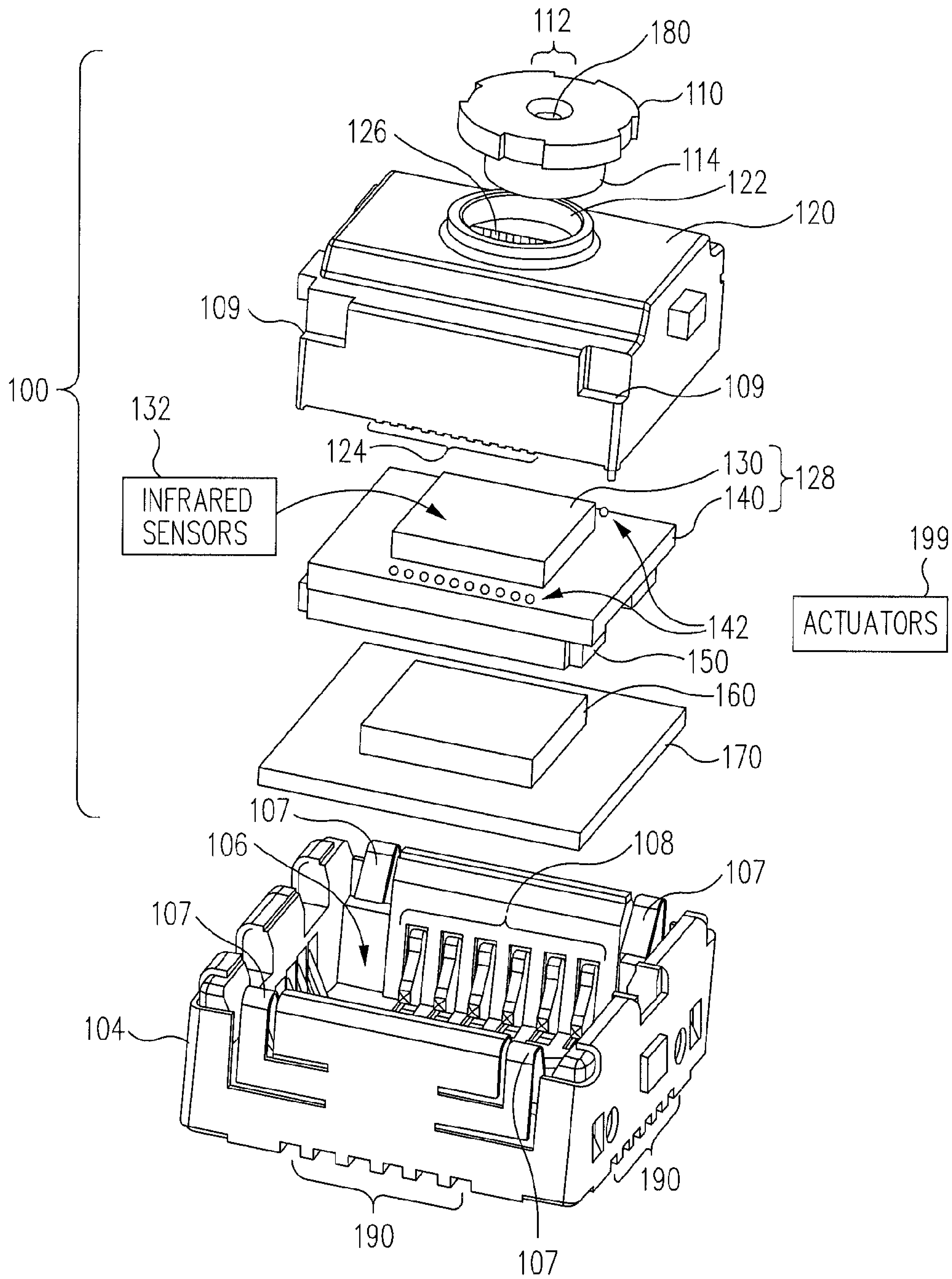

112
180
110
126
114
122
120
109
109
100
132
124
130
128
140
INFRARED SENSORS
199
ACTUATORS
142
150
160
170
107
106
108
107
107
104
190
190
107

FIG. 3

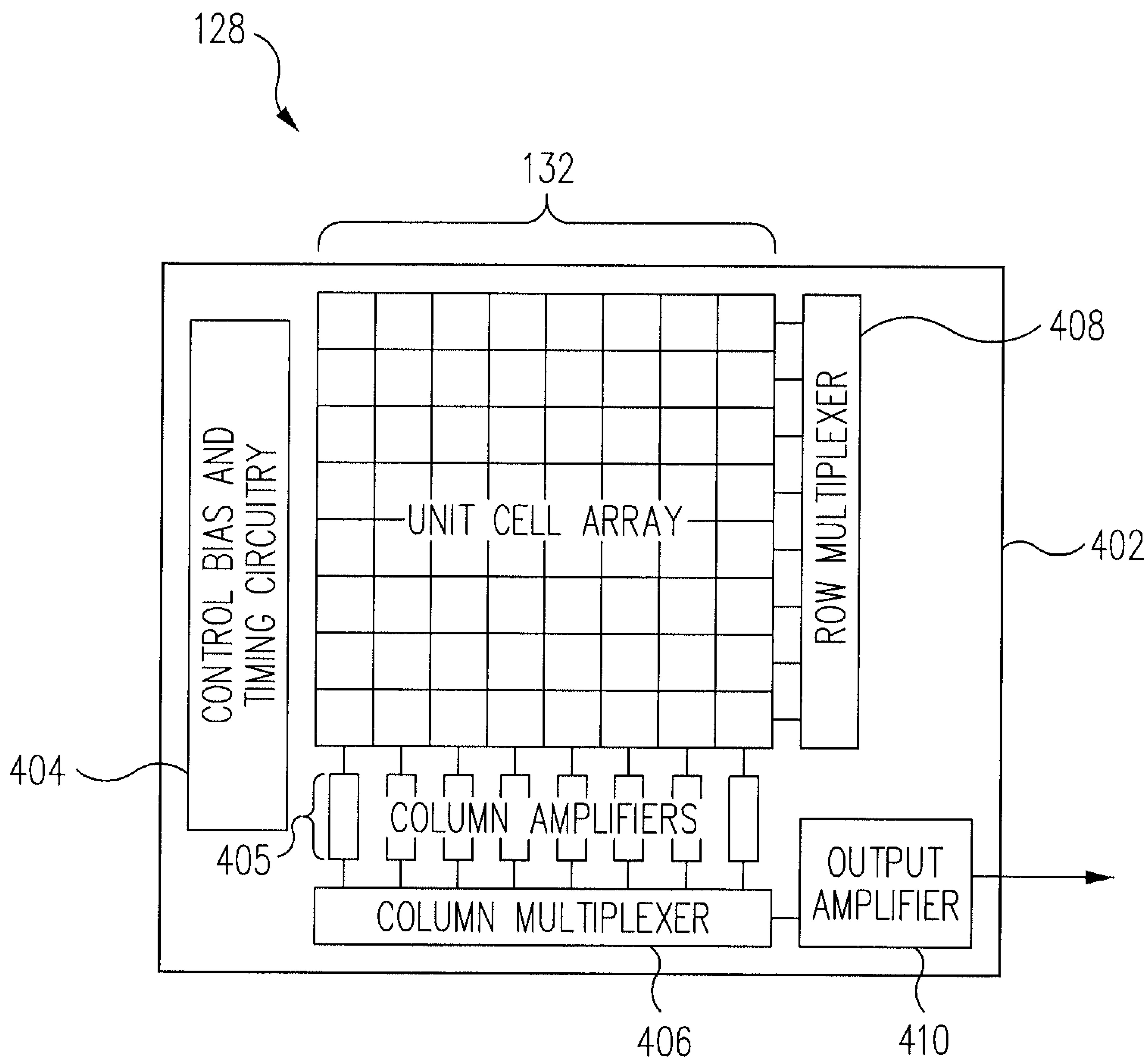

128
132
408
402
404
405
406
410
CONTROL BIAS AND TIMING CIRCUITRY
UNIT CELL ARRAY
ROW MULTIPLEXER
COLUMN AMPLIFIERS
COLUMN MULTIPLEXER
OUTPUT AMPLIFIER

FIG. 4

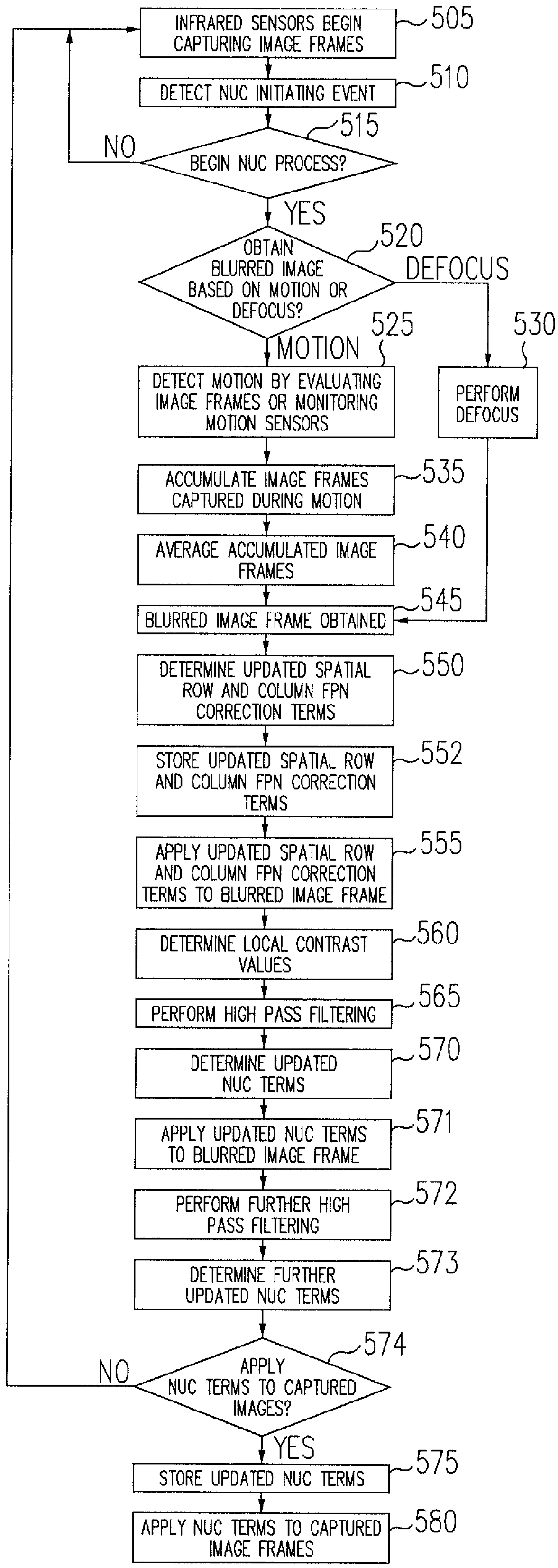

INFRARED SENSORS BEGIN CAPTURING IMAGE FRAMES
505
DETECT NUC INITIATING EVENT
510
BEGIN NUC PROCESS?
515
NO
YES
OBTAIN BLURRED IMAGE BASED ON MOTION OR DEFOCUS?
520
DEFOCUS
MOTION
DETECT MOTION BY EVALUATING IMAGE FRAMES OR MONITORING MOTION SENSORS
525
PERFORM DEFOCUS
530
ACCUMULATE IMAGE FRAMES CAPTURED DURING MOTION
535
AVERAGE ACCUMULATED IMAGE FRAMES
540
BLURRED IMAGE FRAME OBTAINED
545
DETERMINE UPDATED SPATIAL ROW AND COLUMN FPN CORRECTION TERMS
550
STORE UPDATED SPATIAL ROW AND COLUMN FPN CORRECTION TERMS
552
APPLY UPDATED SPATIAL ROW AND COLUMN FPN CORRECTION TERMS TO BLURRED IMAGE FRAME
555
DETERMINE LOCAL CONTRAST VALUES
560
PERFORM HIGH PASS FILTERING
565
DETERMINE UPDATED NUC TERMS
570
APPLY UPDATED NUC TERMS TO BLURRED IMAGE FRAME
571
PERFORM FURTHER HIGH PASS FILTERING
572
DETERMINE FURTHER UPDATED NUC TERMS
573
APPLY NUC TERMS TO CAPTURED IMAGES?
574
NO
YES
STORE UPDATED NUC TERMS
575
APPLY NUC TERMS TO CAPTURED IMAGE FRAMES
580

FIG. 5

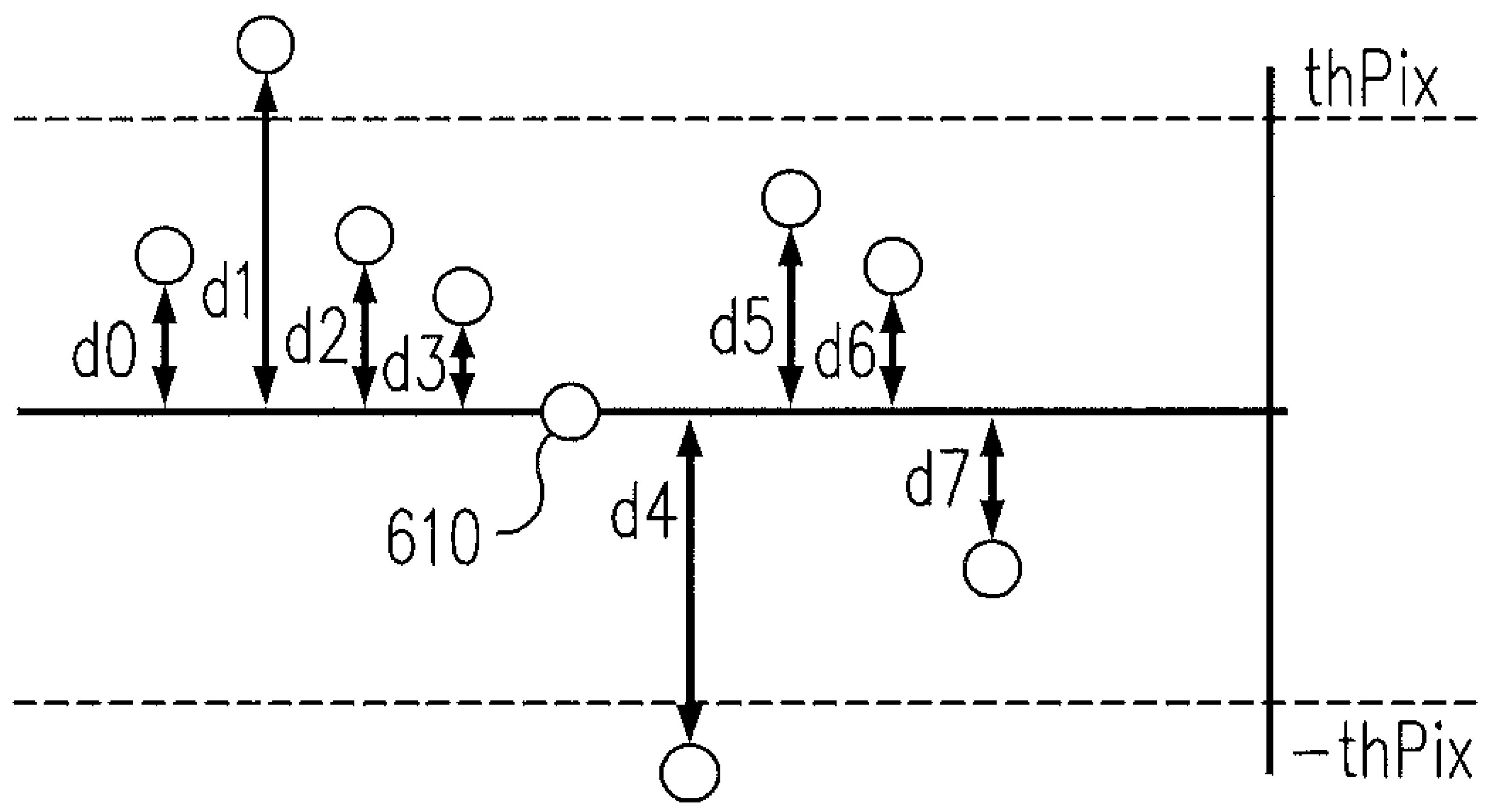

thPix
d0
d1
d2
d3
d5
d6
610
d4
d7
−thPix

FIG. 6

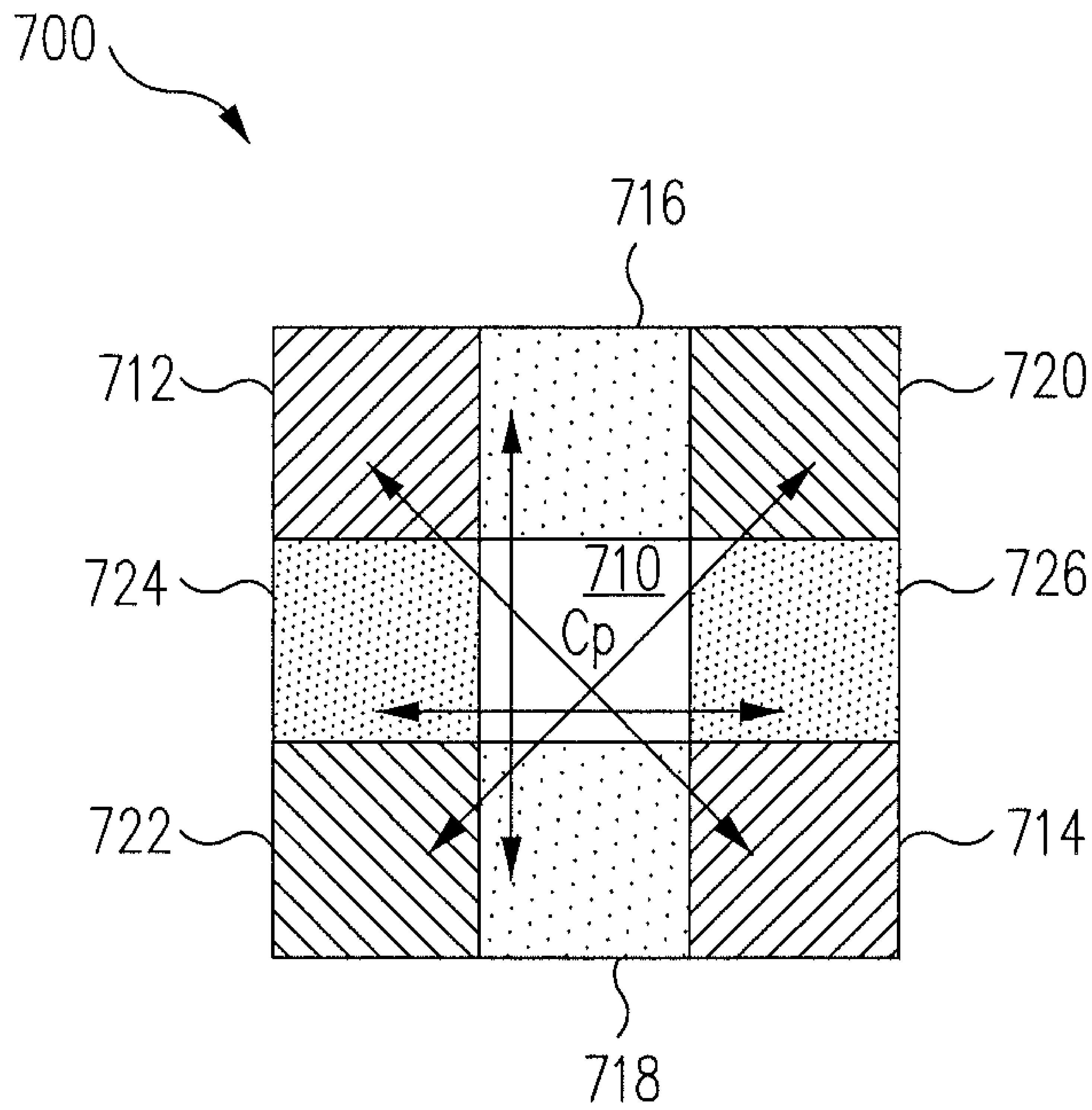

700
716
712
720
724
710
Cp
726
722
714
718

FIG. 7

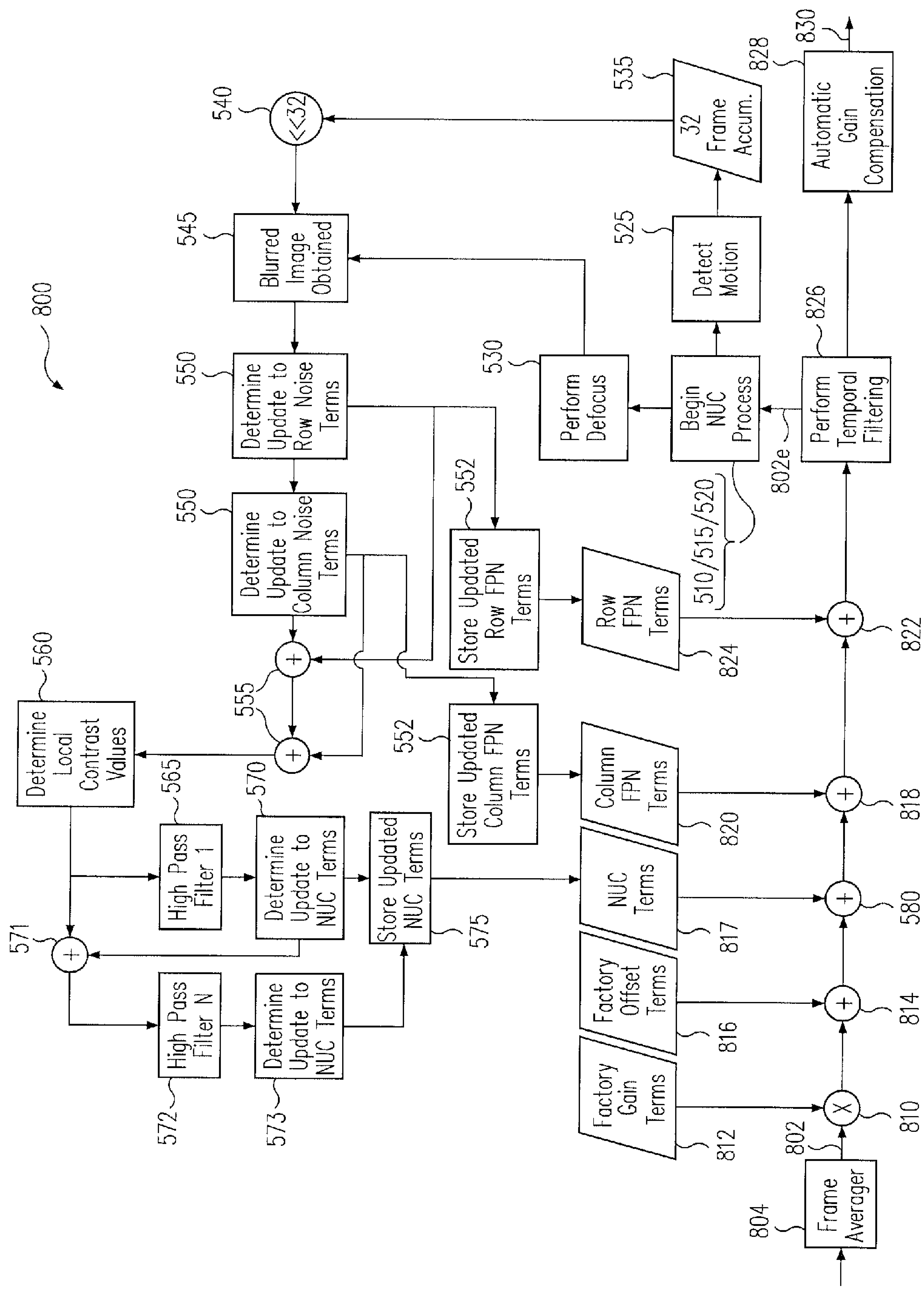

800
Determine Local Contrast Values
560
High Pass Filter 1
565
Determine Update to NUC Terms
570
571
High Pass Filter N
572
Determine Update to NUC Terms
573
Store Updated NUC Terms
575
555
Determine Update to Column Noise Terms
550
Determine Update to Row Noise Terms
550
Blurred Image Obtained
545
<<32
540
Store Updated Column FPN Terms
552
Store Updated Row FPN Terms
552
Perform Defocus
530
Factory Gain Terms
812
Factory Offset Terms
816
NUC Terms
817
Column FPN Terms
820
Row FPN Terms
824
510/515/520
Begin NUC Process
Detect Motion
525
32 Frame Accum.
535
Frame Averager
804
802
810
814
580
818
822
Perform Temporal Filtering
802e
826
Automatic Gain Compensation
828
830

FIG. 8

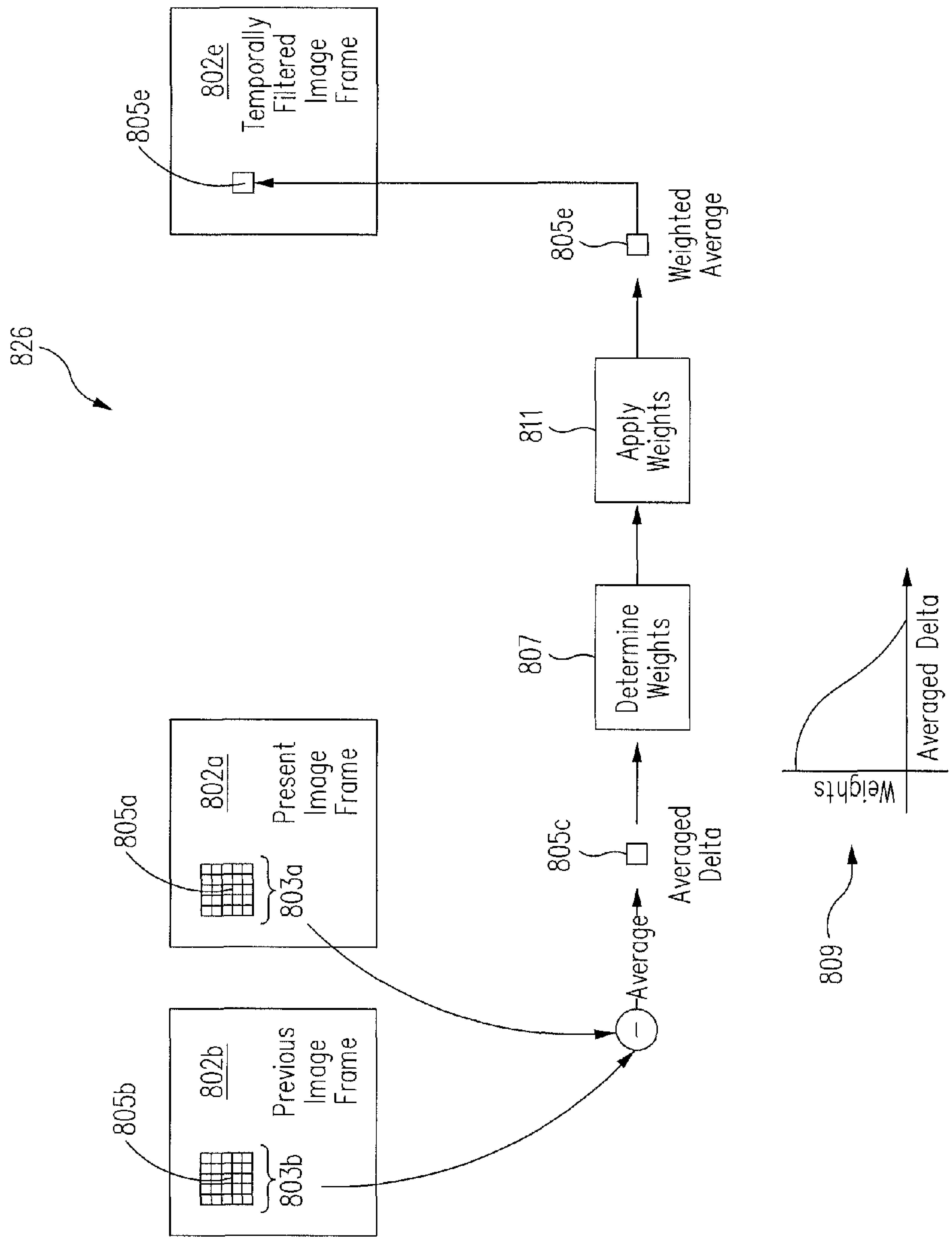
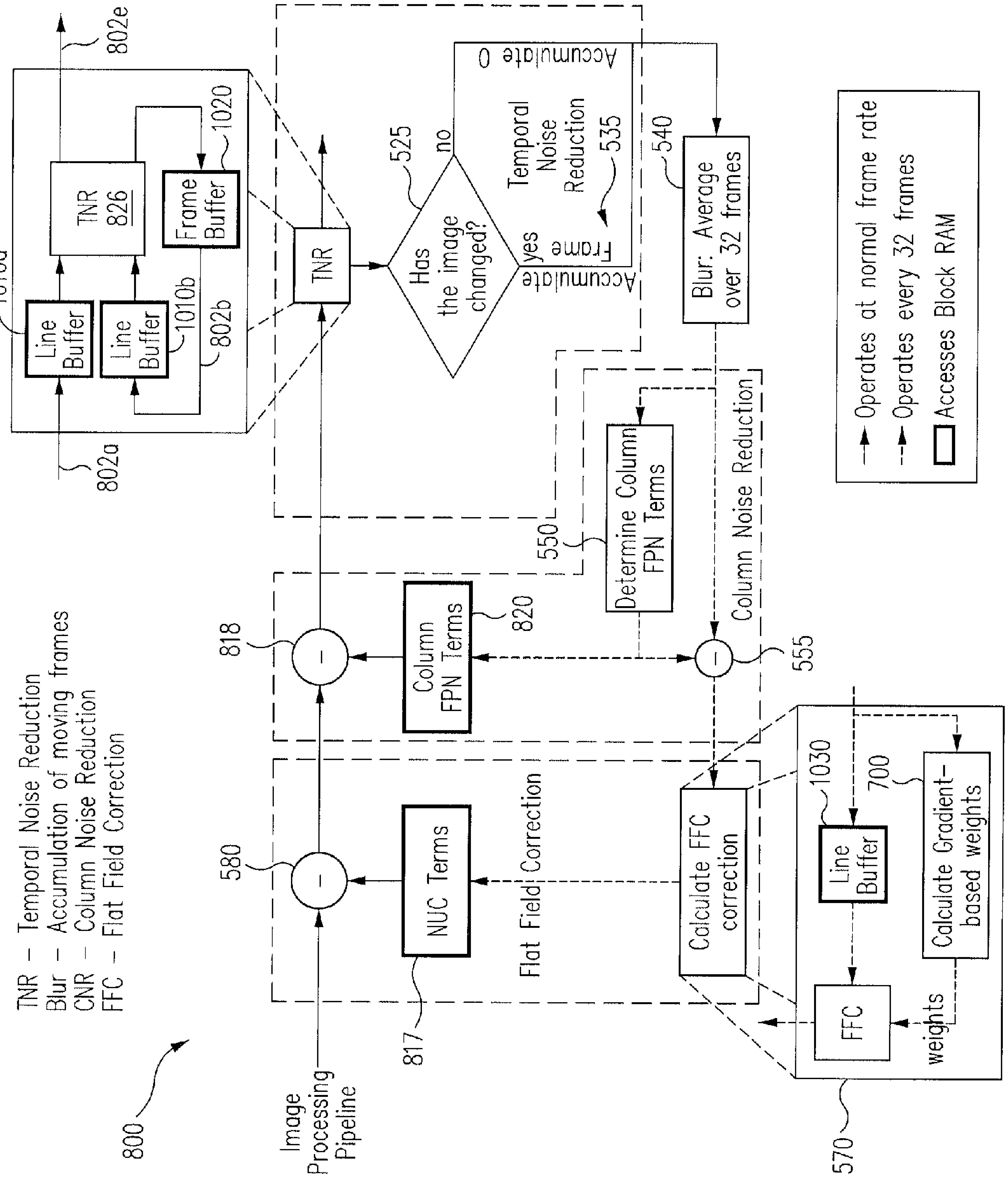

826
802e
Temporally Filtered Image Frame
805e
805e
Weighted Average
811
Apply Weights
807
Determine Weights
805c
Averaged Delta
Average
802a
Present Image Frame
805a
803a
802b
Previous Image Frame
805b
803b
809
Weights
Averaged Delta

FIG. 9



800
TNR – Temporal Noise Reduction
Blur – Accumulation of moving frames
CNR – Column Noise Reduction
FFC – Flat Field Correction
Image Processing Pipeline
817
NUC Terms
580
Flat Field Correction
818
Column FPN Terms
820
Column Noise Reduction
555
550
Determine Column FPN Terms
802a
Line Buffer
1010a
Line Buffer
1010b
802b
TNR 826
Frame Buffer
1020
802e
TNR
Has the image changed?
525
no
yes
Accumulate 0
Temporal Noise Reduction
535
Accumulate Frame
540
Blur: Average over 32 frames
Calculate FFC correction
1030
Line Buffer
700
Calculate Gradient-based weights
FFC
weights
570
Operates at normal frame rate
Operates every 32 frames
Accesses Block RAM

FIG. 10

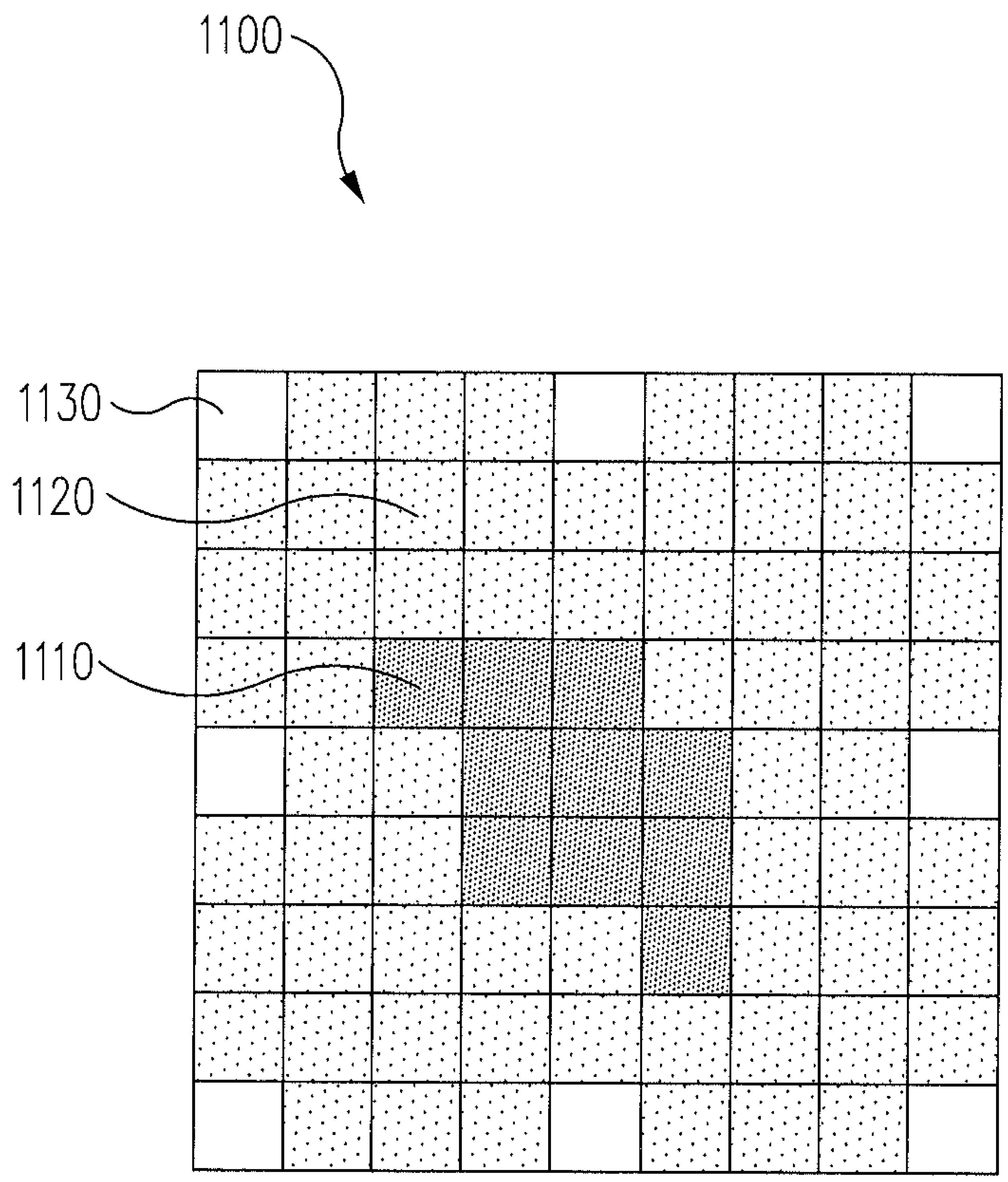
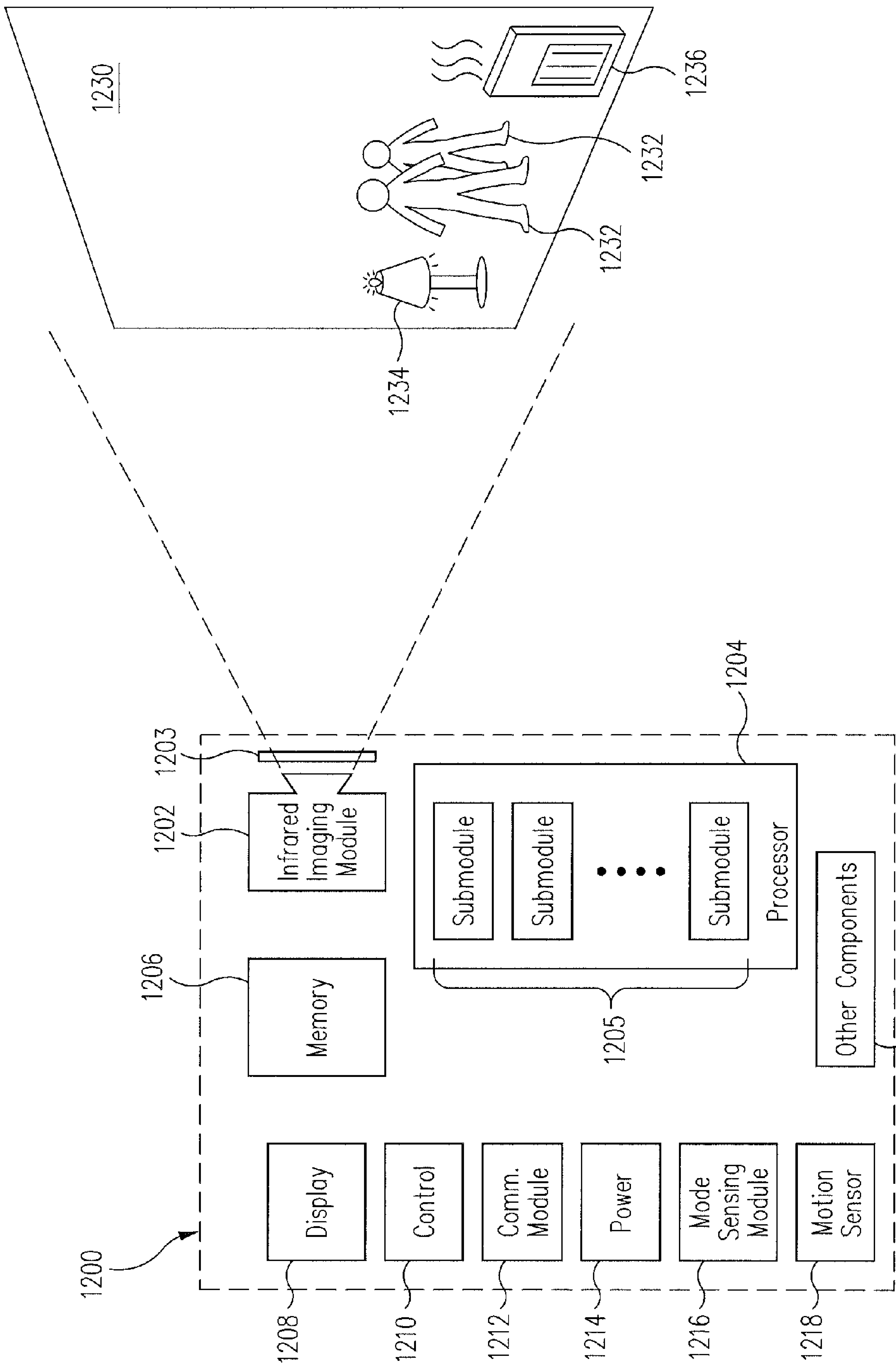


FIG. 11



1230
1232
1232
1234
1236
1200
1202
1203
1204
1205
1206
Infrared Imaging Module
Memory
Submodule
Submodule
Submodule
Processor
Other Components
1220
Display
Control
Comm. Module
Power
Mode Sensing Module
Motion Sensor
1208
1210
1212
1214
1216
1218

FIG. 12

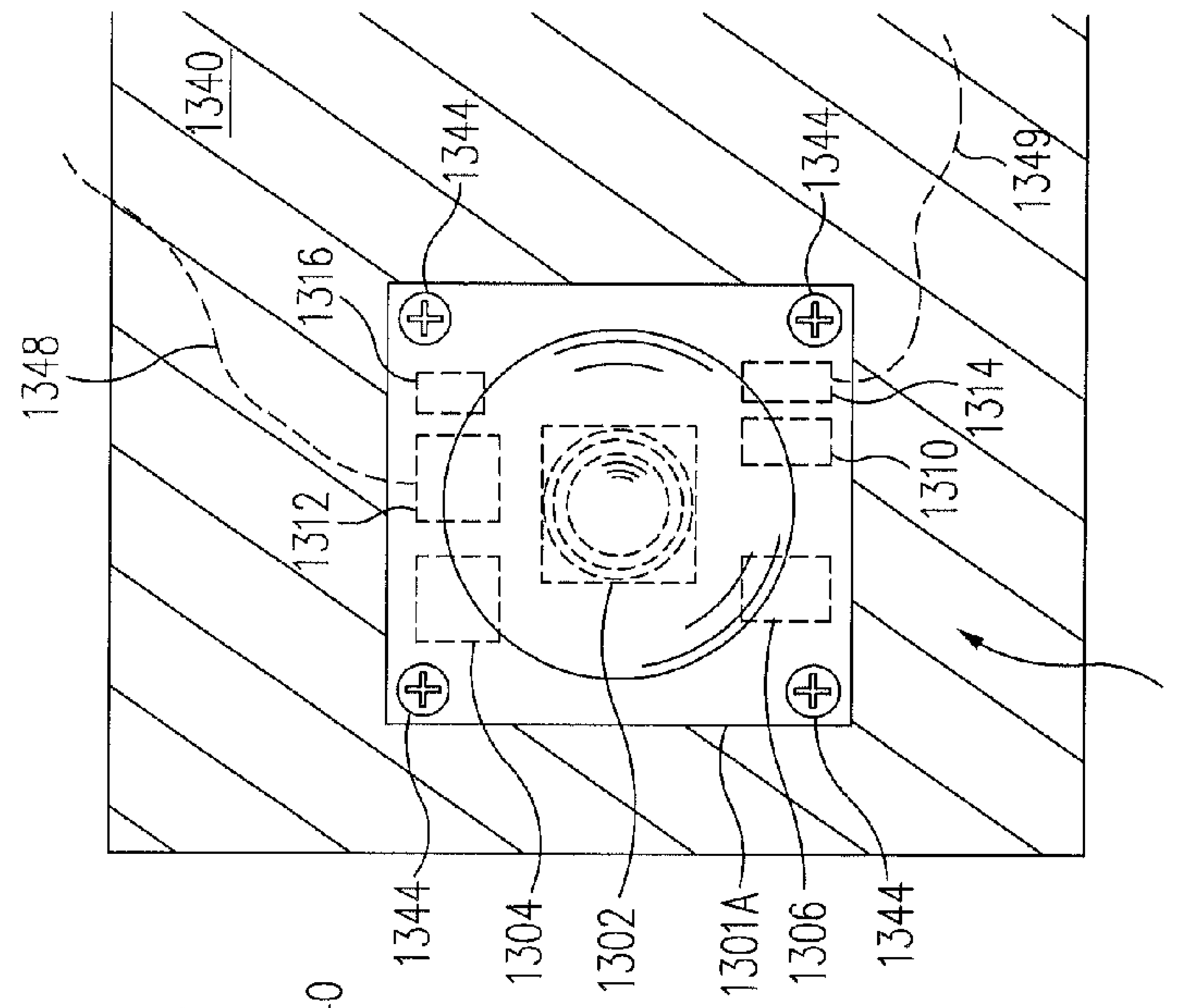


FIG. 13B

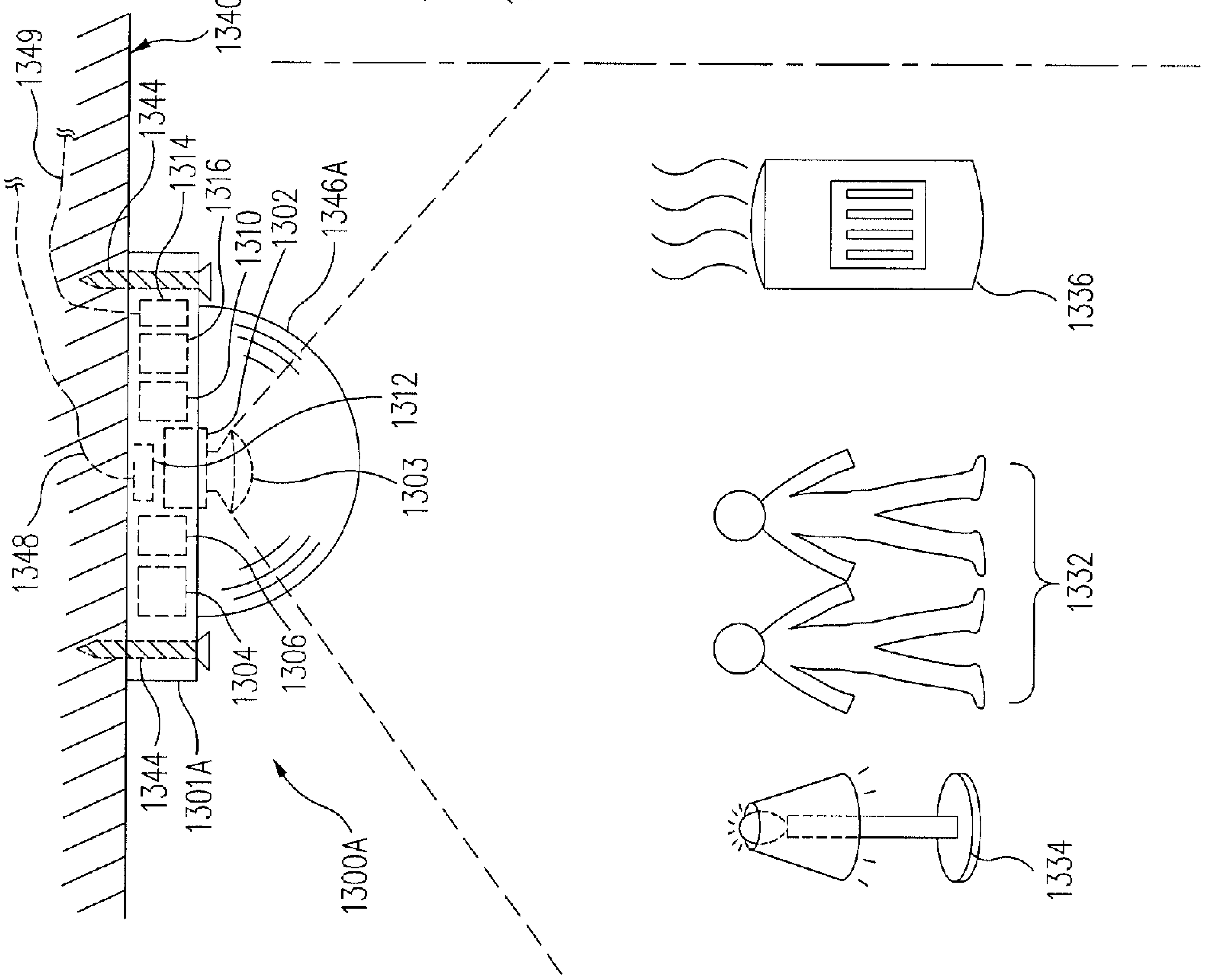


FIG. 13A

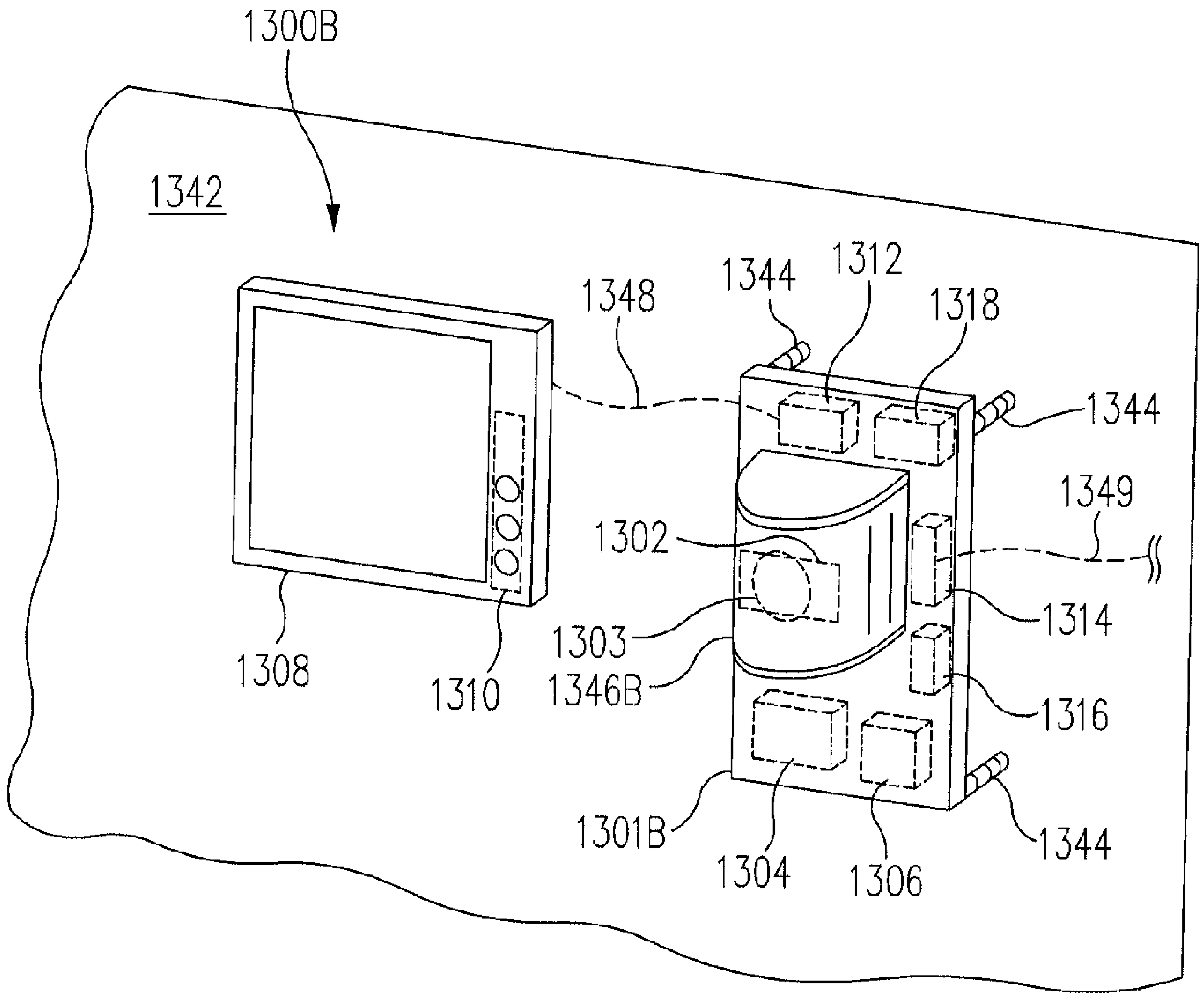


FIG. 13C

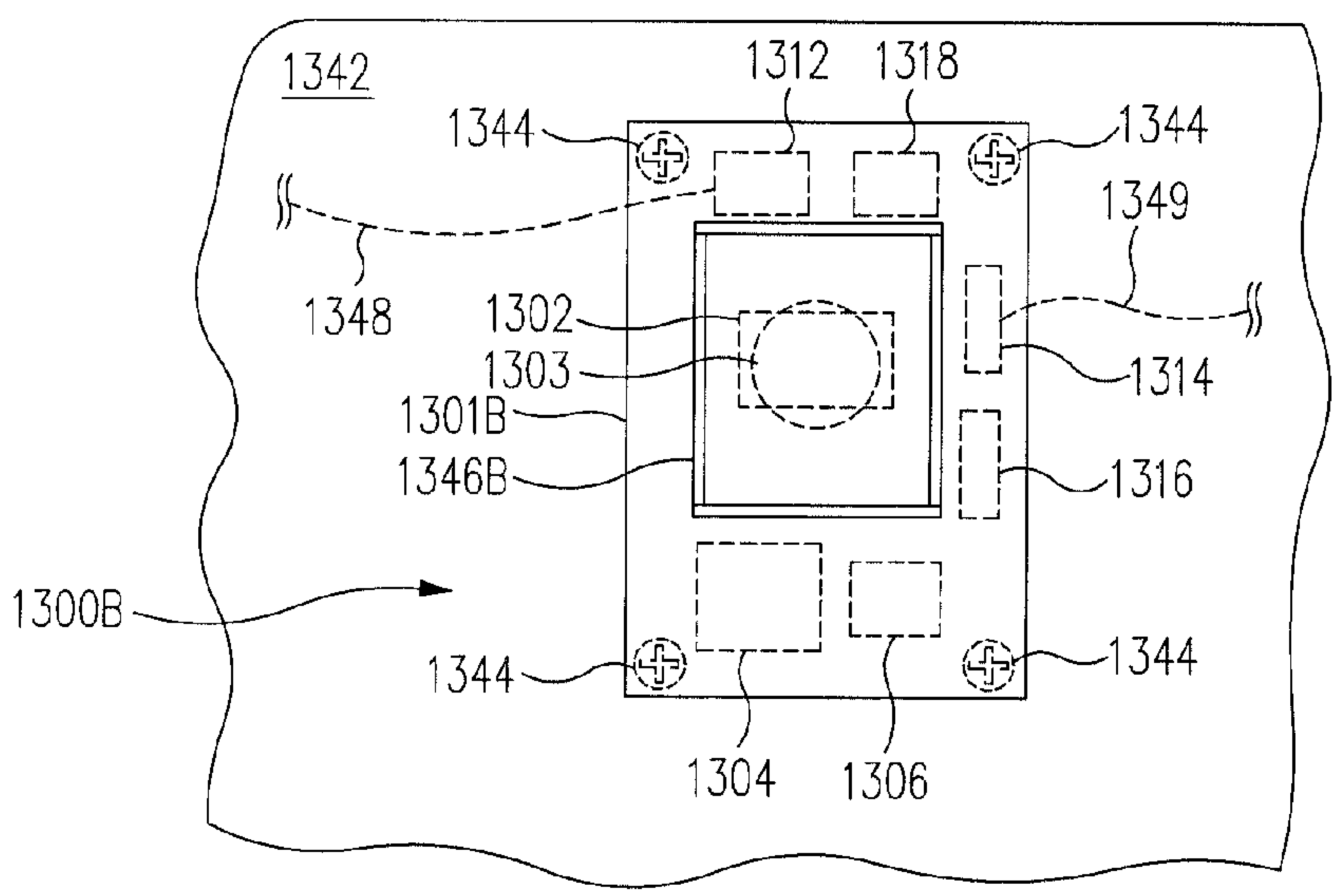


FIG. 13D

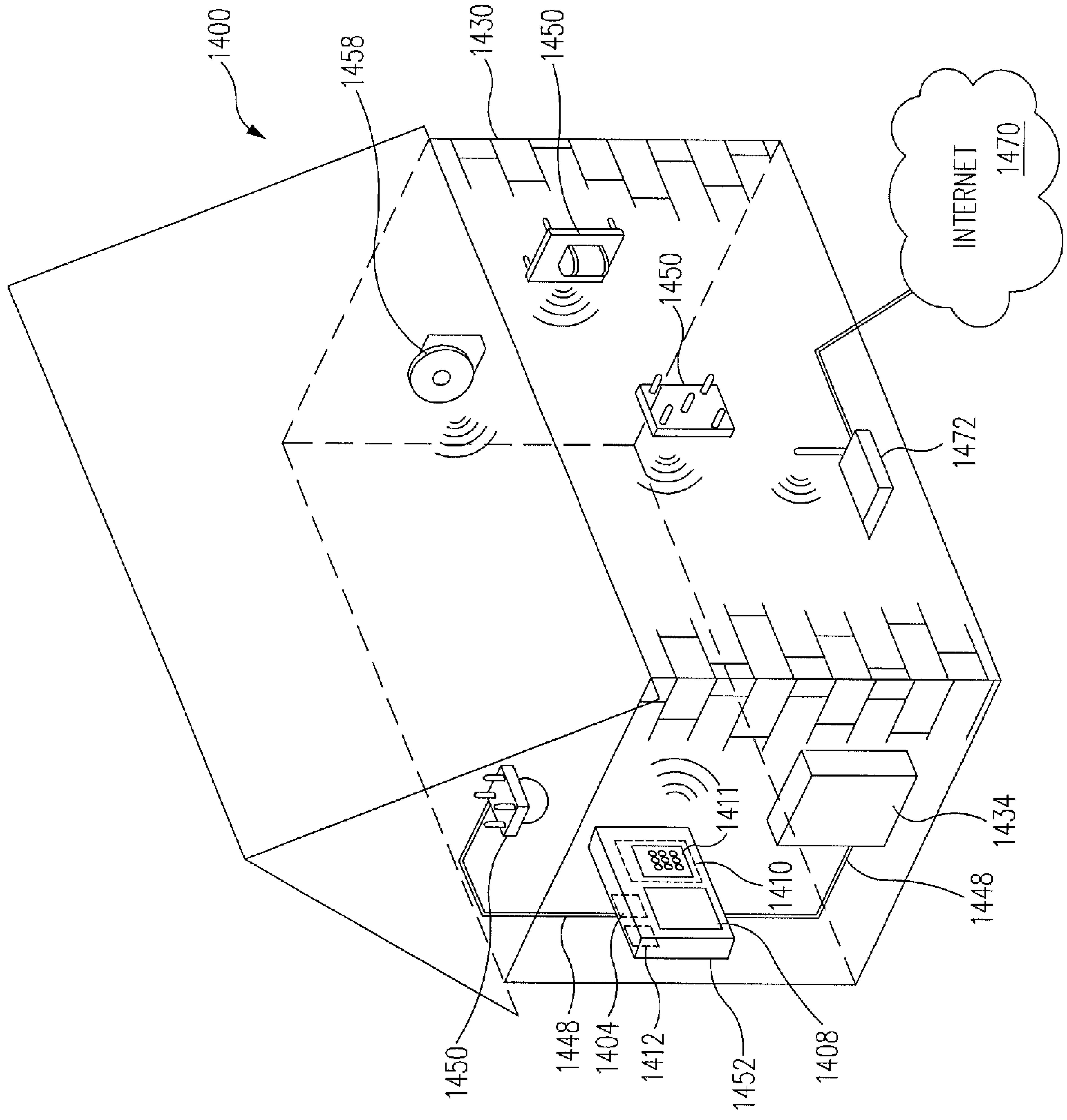

1400
1458
1430
1450
INTERNET
1470
1450
1472
1411
1410
1434
1448
1450
1448
1404
1412
1452
1408

FIG. 14

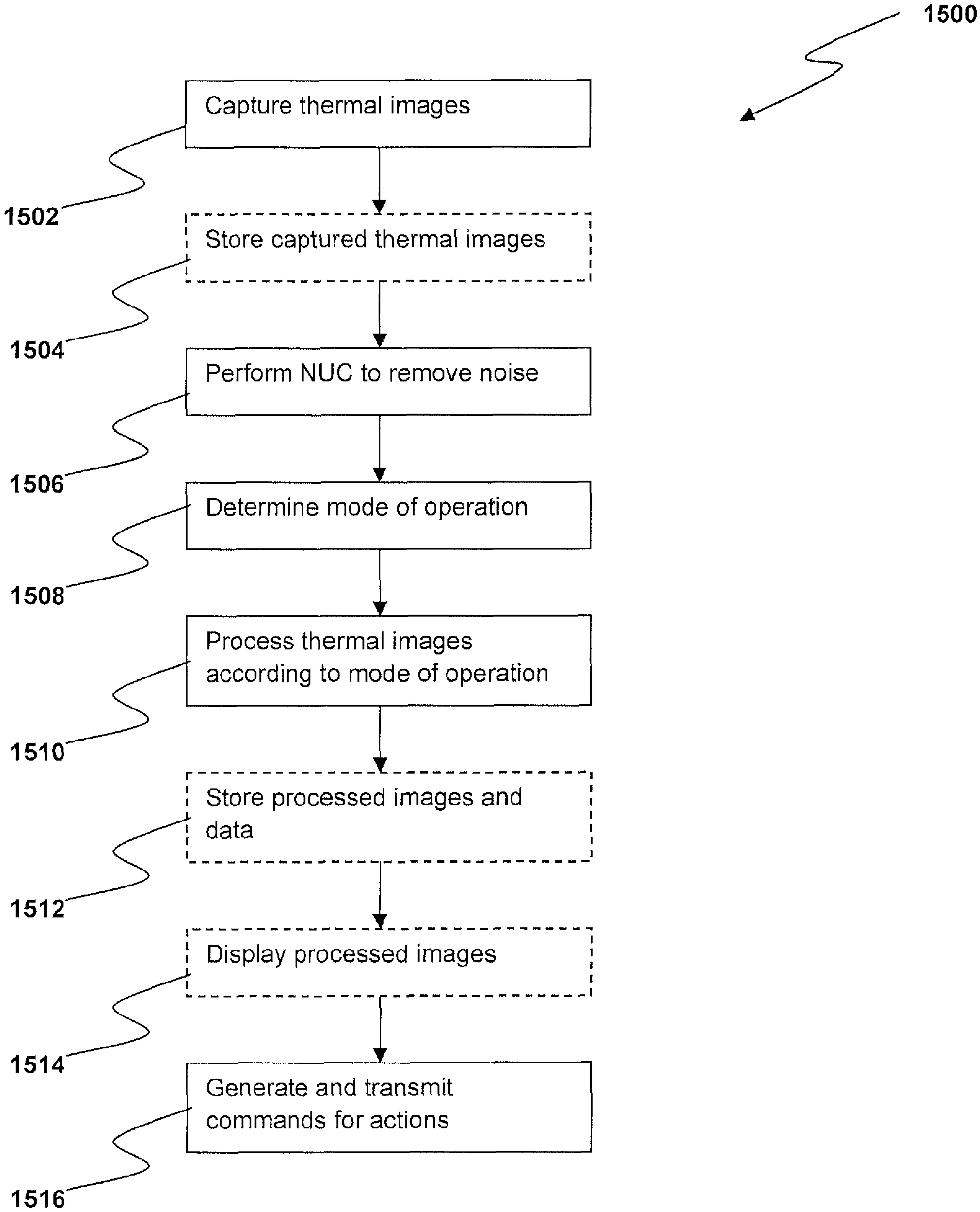

1500
Capture thermal images
1502
Store captured thermal images
1504
Perform NUC to remove noise
1506
Determine mode of operation
1508
Process thermal images according to mode of operation
1510
Store processed images and data
1512
Display processed images
1514
Generate and transmit commands for actions
1516

FIG. 15

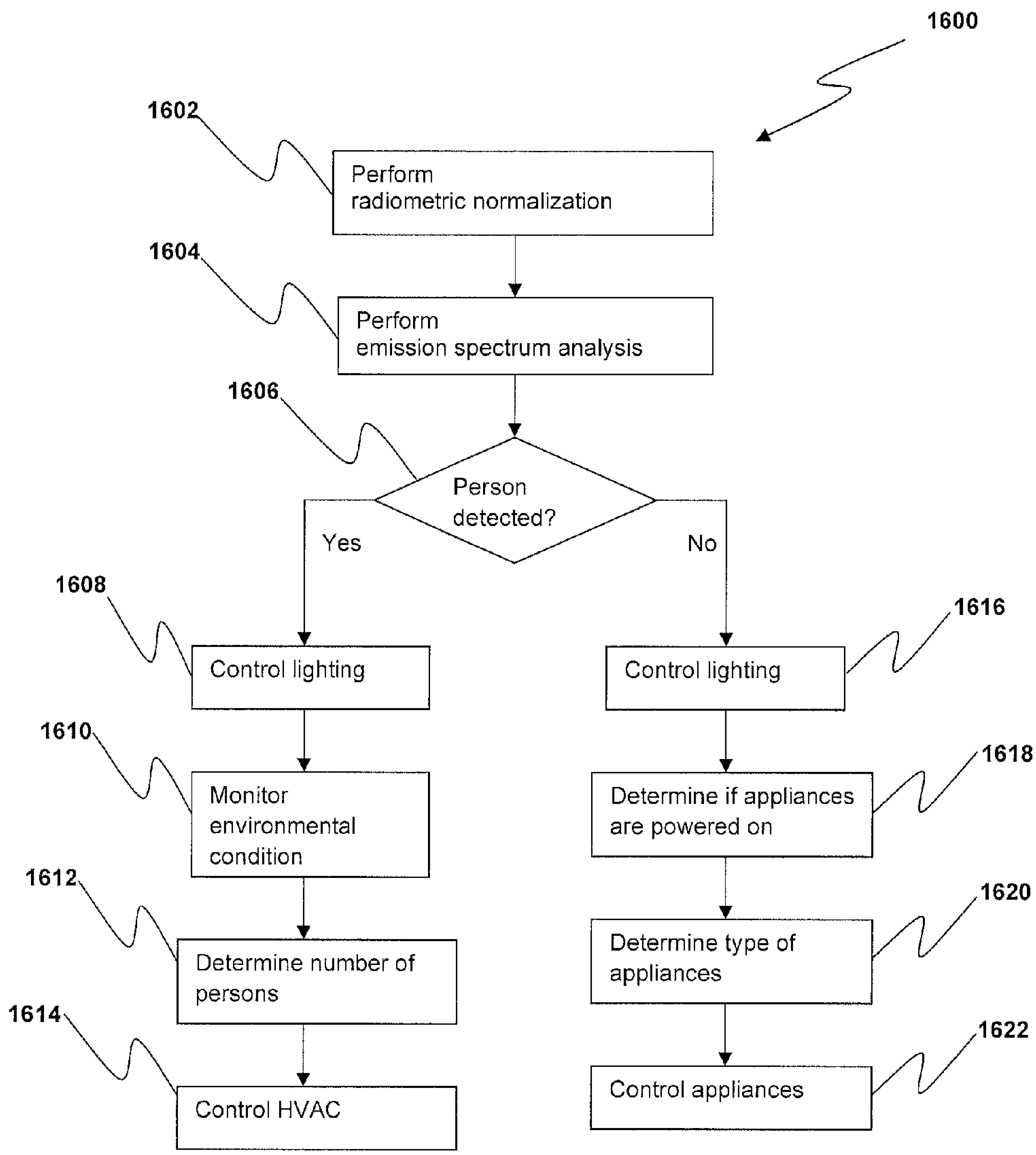

1600
1602
Perform radiometric normalization
1604
Perform emission spectrum analysis
1606
Person detected?
Yes
No
1608
Control lighting
1610
Monitor environmental condition
1612
Determine number of persons
1614
Control HVAC
1616
Control lighting
1618
Determine if appliances are powered on
1620
Determine type of appliances
1622
Control appliances

FIG. 16

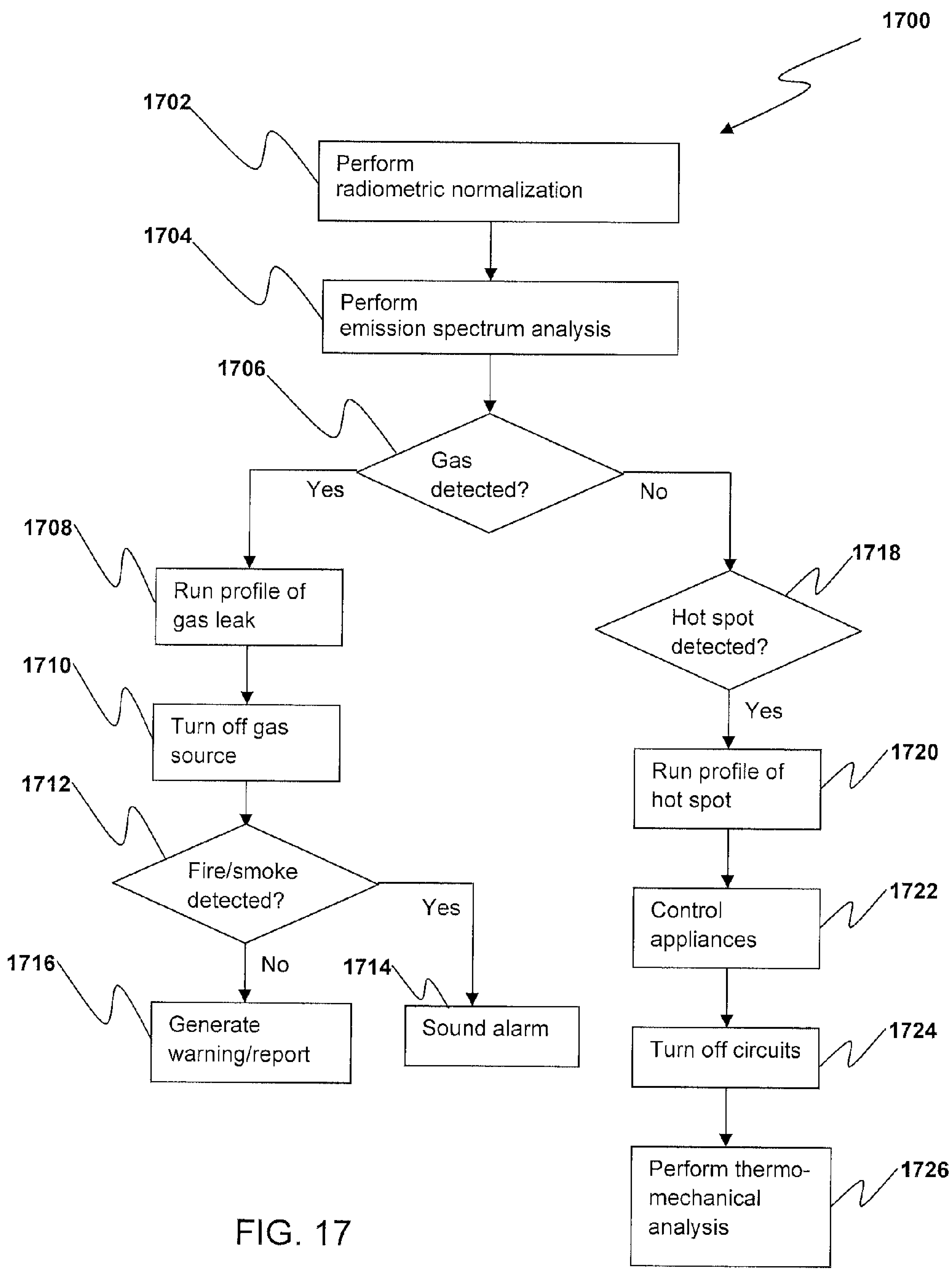

1700
1702
Perform
radiometric normalization
1704
Perform
emission spectrum analysis
1706
Gas
detected?
Yes
No
1708
Run profile of
gas leak
1710
Turn off gas
source
1712
Fire/smoke
detected?
Yes
No
1714
Sound alarm
1716
Generate
warning/report
1718
Hot spot
detected?
Yes
1720
Run profile of
hot spot
1722
Control
appliances
1724
Turn off circuits
1726
Perform thermo-
mechanical
analysis

FIG. 17

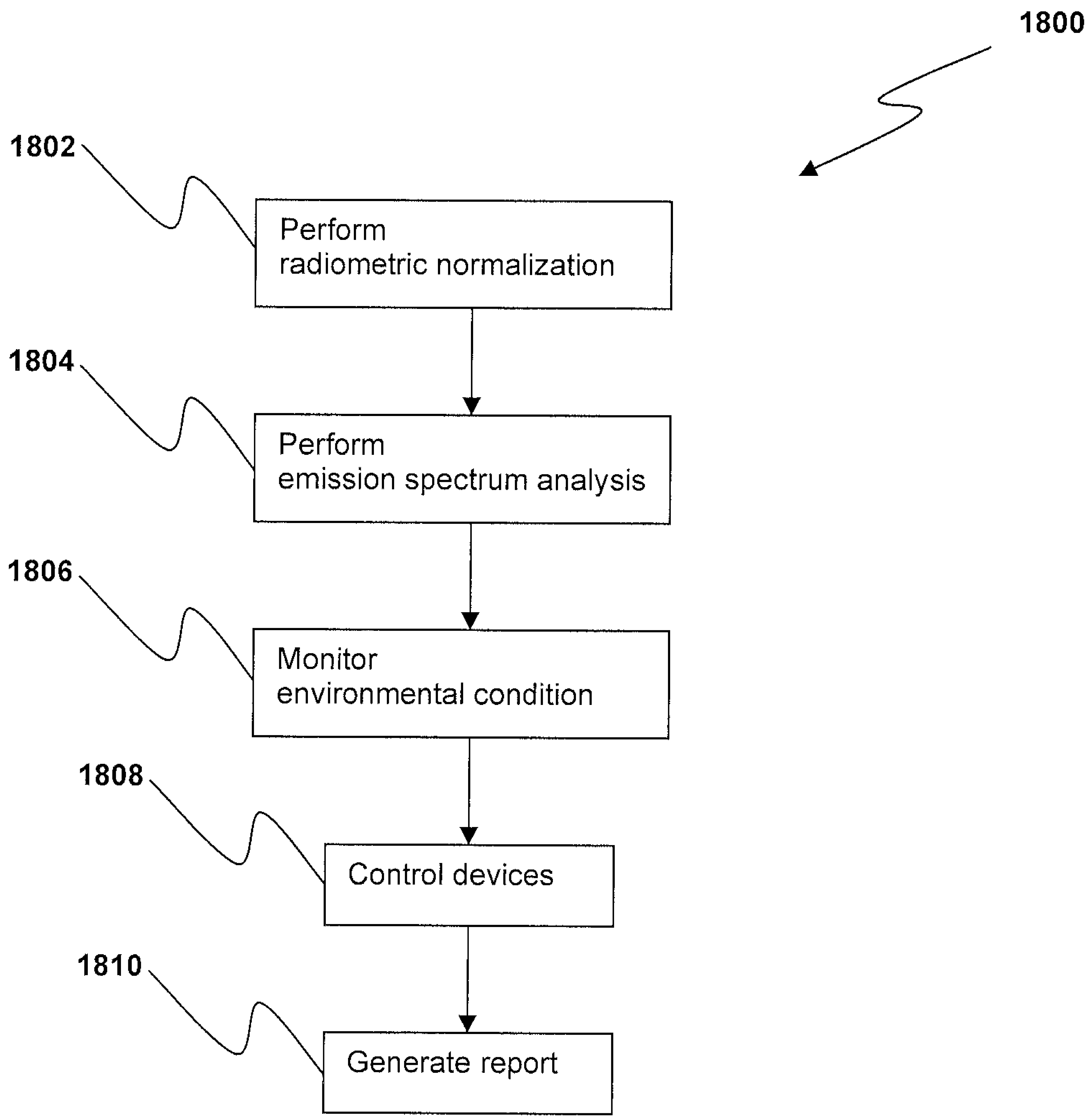

1800
1802
Perform
radiometric normalization
1804
Perform
emission spectrum analysis
1806
Monitor
environmental condition
1808
Control devices
1810
Generate report

FIG. 18

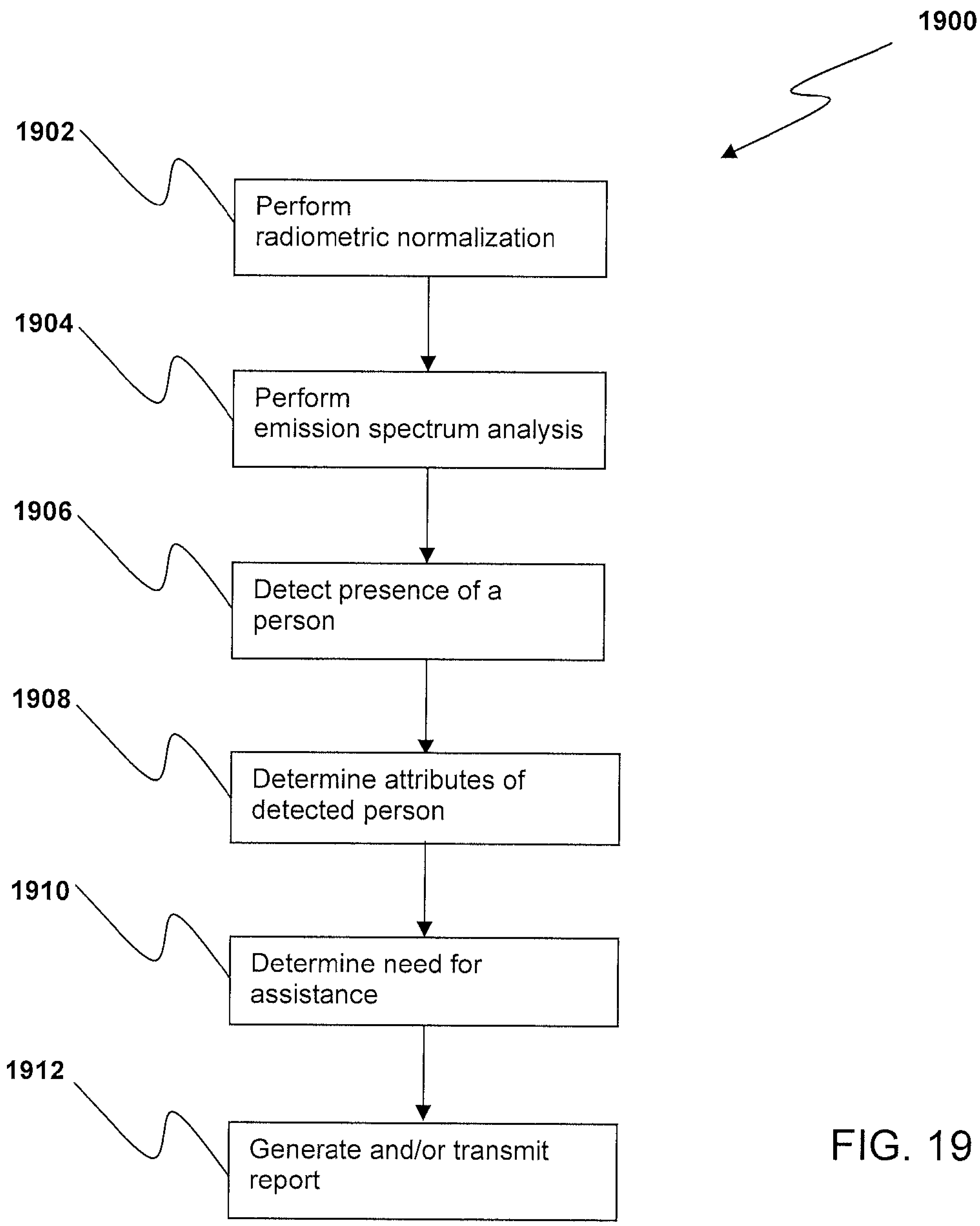

1900
1902
Perform
radiometric normalization
1904
Perform
emission spectrum analysis
1906
Detect presence of a
person
1908
Determine attributes of
detected person
1910
Determine need for
assistance
1912
Generate and/or transmit
report

FIG. 19

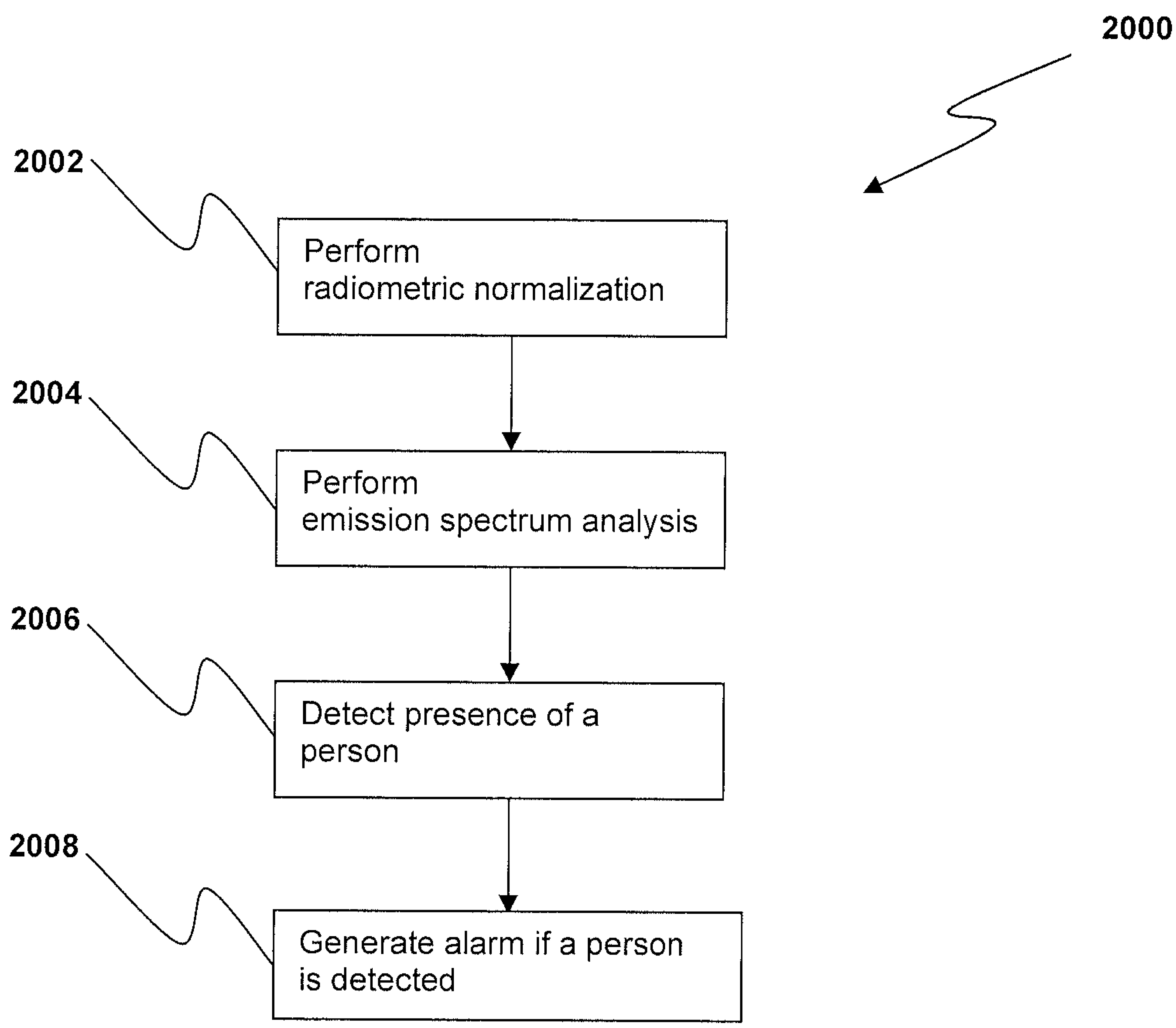

2000
2002
Perform
radiometric normalization
2004
Perform
emission spectrum analysis
2006
Detect presence of a
person
2008
Generate alarm if a person
is detected

FIG. 20

MONITOR AND CONTROL SYSTEMS AND METHODS FOR OCCUPANT SAFETY AND ENERGY EFFICIENCY OF STRUCTURES

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application claims the benefit of U.S. Provisional Patent Application No. 61/651,976 filed May 25, 2012 and entitled "MONITOR AND CONTROL SYSTEMS AND METHODS FOR OCCUPANT SAFETY AND ENERGY EFFICIENCY OF STRUCTURES" which is hereby incorporated by reference in its entirety.

This patent application is a continuation-in-part of International Patent Application No. PCT/US2012/041744 filed Jun. 8, 2012 and entitled "LOW POWER AND SMALL FORM FACTOR INFRARED IMAGING," which is incorporated herein by reference in its entirety.

International Patent Application No. PCT/US2012/041744 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/656,889 filed Jun. 7, 2012 and entitled "LOW POWER AND SMALL FORM FACTOR INFRARED IMAGING," which are incorporated herein by reference in their entirety.

International Patent Application No. PCT/US2012/041744 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/545,056 filed Oct. 7, 2011 and entitled "NON-UNIFORMITY CORRECTION TECHNIQUES FOR INFRARED IMAGING DEVICES," which are incorporated herein by reference in their entirety.

International Patent Application No. PCT/US2012/041744 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/495,873 filed Jun. 10, 2011 and entitled "INFRARED CAMERA PACKAGING SYSTEMS AND METHODS," which are incorporated herein by reference in their entirety.

International Patent Application No. PCT/US2012/041744 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/495,879 filed Jun. 10, 2011 and entitled "INFRARED CAMERA SYSTEM ARCHITECTURES," which are incorporated herein by reference in their entirety.

International Patent Application No. PCT/US2012/041744 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/495,888 filed Jun. 10, 2011 and entitled "INFRARED CAMERA CALIBRATION TECHNIQUES," which are incorporated herein by reference in their entirety.

This patent application is a continuation-in-part of International Patent Application No. PCT/US2012/041749 filed Jun. 8, 2012 and entitled "NON-UNIFORMITY CORRECTION TECHNIQUES FOR INFRARED IMAGING DEVICES," which is incorporated herein by reference in its entirety.

International Patent Application No. PCT/US2012/041749 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/545,056 filed Oct. 7, 2011 and entitled "NON-UNIFORMITY CORRECTION TECHNIQUES FOR INFRARED IMAGING DEVICES," which are incorporated herein by reference in their entirety.

International Patent Application No. PCT/US2012/041749 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/495,873 filed Jun. 10, 2011 and entitled "INFRARED CAMERA PACKAGING SYSTEMS AND METHODS," which are incorporated herein by reference in their entirety.

International Patent Application No. PCT/US2012/041749 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/495,879 filed Jun. 10, 2011 and entitled "INFRARED CAMERA SYSTEM ARCHITECTURES," which are incorporated herein by reference in their entirety.

International Patent Application No. PCT/US2012/041749 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/495,888 filed Jun. 10, 2011 and entitled "INFRARED CAMERA CALIBRATION TECHNIQUES," which are incorporated herein by reference in their entirety.

This patent application is a continuation-in-part of International Patent Application No. PCT/US2012/041739 filed Jun. 8, 2012 and entitled "INFRARED CAMERA SYSTEM ARCHITECTURES," which is hereby incorporated by reference in its entirety.

International Patent Application No. PCT/US2012/041739 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/495,873 filed Jun. 10, 2011 and entitled "INFRARED CAMERA PACKAGING SYSTEMS AND METHODS," which are incorporated herein by reference in their entirety.

International Patent Application No. PCT/US2012/041739 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/495,879 filed Jun. 10, 2011 and entitled "INFRARED CAMERA SYSTEM ARCHITECTURES," which are incorporated herein by reference in their entirety.

International Patent Application No. PCT/US2012/041739 claims priority to and the benefit of U.S. Provisional Patent Application No. 61/495,888 filed Jun. 10, 2011 and entitled "INFRARED CAMERA CALIBRATION TECHNIQUES," which are incorporated herein by reference in their entirety.

This patent application is a continuation-in-part of U.S. patent application Ser. No. 13/622,178 filed Sep. 18, 2012 and entitled "SYSTEMS AND METHODS FOR PROCESSING INFRARED IMAGES," which is a continuation-in-part of U.S. patent application Ser. No. 13/529,772 filed Jun. 21, 2012 and entitled "SYSTEMS AND METHODS FOR PROCESSING INFRARED IMAGES," which is a continuation of U.S. patent application Ser. No. 12/396,340 filed Mar. 2, 2009 and entitled "SYSTEMS AND METHODS FOR PROCESSING INFRARED IMAGES," which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

One or more embodiments of the invention relate generally to thermal imaging devices and more particularly, for example, to the use of thermal images to monitor and control occupant safety and energy efficiency of structures.

BACKGROUND

There is a movement to increase energy efficiency of residential dwellings and commercial buildings. For example, governments are increasingly enacting laws and green building codes that require new buildings to conform to more stringent energy efficiency standards and to reduce their carbon footprint. Similarly, public utilities are introducing incentive programs to encourage residential consumers to reduce their utility usage through conservation efforts and increased energy efficiency. In addition, to enhance home safety, homes are required to have fire detectors, smoke detectors, and increasingly carbon monoxide (CO) detectors.

While mandating higher energy efficiency and safety standards are important, they also require installations of various types of devices, sensors, and detectors in homes and buildings. Conventionally, a room may have a motion detector to detect for the presence of people in the room to automatically control lighting, a thermostat to control the heating, venting, and air conditioning (HVAC) system, other power sensors to control power usage, a fire alarm, a smoke detector, and a CO detector. Such conventional detectors and sensors are not capable of acquiring data with the detail necessary to enable high-level analytics or detection of multiple types of events. For example, conventional passive infrared (PIR) motion detectors are built with only one to four pyroelectric cells, which are only good for detecting changes in thermal energy in a given area.

As such, such conventional devices, sensors, and detectors are not cost-effective, because many different devices, sensors, and detectors are required to provide a comprehensive monitoring and control. Further, even when many different devices, sensors, and detectors are installed, they still may not provide the detailed data necessary for intelligent monitoring and control suitable for modern green buildings. As the movement toward greener and safer buildings gathers momentum, these conventional sensors and detectors may become even more cost prohibitive and yet insufficient.

SUMMARY

Various systems and methods are disclosed for monitoring and controlling using small infrared imaging modules to enhance occupant safety and energy efficiency of buildings and structures. In one example, thermal images captured by infrared imaging modules may be analyzed to detect presence of persons, identify and classify power-consuming objects, and monitor environmental conditions. Based on the processed thermal images, various power-consuming objects (e.g., an HVAC system, lighting, a water heater, and other appliances) may be controlled to increase energy efficiency. In another example, thermal images captured by infrared imaging modules may be analyzed to detect various hazardous conditions, such as a combustible gas leak, a CO gas leak, a water leak, fire, smoke, and, an electrical hotspot. If such hazardous conditions are detected, an appropriate warning may be generated and/or various objects may be controlled to remedy the conditions.

In one embodiment, a monitor and control system includes one or more infrared image sensors comprising a focal plane array (FPA) configured to capture a thermal image of an area; a processor configured to process the thermal image to detect presence of one or more persons in the area, and to generate control signals to control future power usage of one or more objects based at least in part on the detected presence or non-presence of one or more persons; and a communication module configured to transmit the control signals to control the future power usage of the one or more objects.

In another embodiment, a monitor and control method includes capturing, at a focal plane array of an infrared imaging module, a thermal image of an area; processing the thermal image to detect presence of one or more persons in the area; generating control signals to control future power usage of one or more objects based at least in part on the detected presence or non-presence of one or more persons; and communicating the control signals to the objects over a network.

The scope of the invention is defined by the claims, which are incorporated into this section by reference. A more complete understanding of embodiments of the invention will be afforded to those skilled in the art, as well as a realization of additional advantages thereof, by a consideration of the following detailed description of one or more embodiments. Reference will be made to the appended sheets of drawings that will first be described briefly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an infrared imaging module configured to be implemented in a host device in accordance with an embodiment of the disclosure.

FIG. **2** illustrates an assembled infrared imaging module in accordance with an embodiment of the disclosure.

FIG. **3** illustrates an exploded view of an infrared imaging module juxtaposed over a socket in accordance with an embodiment of the disclosure.

FIG. **4** illustrates a block diagram of infrared sensor assembly including an array of infrared sensors in accordance with an embodiment of the disclosure.

FIG. **5** illustrates a flow diagram of various operations to determine NUC terms in accordance with an embodiment of the disclosure.

FIG. **6** illustrates differences between neighboring pixels in accordance with an embodiment of the disclosure.

FIG. **7** illustrates a flat field correction technique in accordance with an embodiment of the disclosure.

FIG. **8** illustrates various image processing techniques of FIG. **5** and other operations applied in an image processing pipeline in accordance with an embodiment of the disclosure.

FIG. **9** illustrates a temporal noise reduction process in accordance with an embodiment of the disclosure.

FIG. **10** illustrates particular implementation details of several processes of the image processing pipeline of FIG. **6** in accordance with an embodiment of the disclosure.

FIG. **11** illustrates spatially correlated FPN in a neighborhood of pixels in accordance with an embodiment of the disclosure.

FIG. **12** illustrates a block diagram of a monitor and control system for enhancing occupant safety and energy efficiency in accordance with one embodiment of the disclosure.

FIGS. **13**A-**13**B illustrate various schematic views of a monitor and control system for enhancing occupant safety and energy efficiency in accordance with another embodiment of the disclosure.

FIGS. **13**C-**13**D illustrate various schematic views of a monitor and control system for enhancing occupant safety and energy efficiency in accordance with yet another embodiment of the disclosure.

FIG. **14** illustrates a schematic view of a network system for monitoring and controlling of a structure in accordance with an embodiment of the disclosure.

FIG. **15** illustrates a flowchart of a process for monitoring and controlling to enhance occupant safety and energy efficiency in accordance with an embodiment of the disclosure.

FIG. **16** illustrates a flowchart of a process for monitoring and controlling power usage in an area in accordance with an embodiment of the disclosure.

FIG. **17** illustrates a flowchart of a process for detecting hazardous conditions in an area in accordance with an embodiment of the disclosure.

FIG. **18** illustrates a flowchart of a process for monitoring and analyzing energy usage and environmental condition for maximizing energy efficiency in a structure in accordance with an embodiment of the disclosure.

FIG. **19** illustrates a flowchart of a process for monitoring and analyzing thermal image data and reporting persons that may need assistance in accordance with an embodiment of the disclosure.

FIG. **20** illustrates a flowchart of a process for monitoring and analyzing thermal image data and reporting for security applications in accordance with an embodiment of the disclosure.

Embodiments of the invention and their advantages are best understood by referring to the detailed description that follows. It should be appreciated that like reference numerals are used to identify like elements illustrated in one or more of the figures.

DETAILED DESCRIPTION

FIG. **1** illustrates an infrared imaging module **100** (e.g., an infrared camera or an infrared imaging device) configured to be implemented in a host device **102** in accordance with an embodiment of the disclosure. Infrared imaging module **100** may be implemented, for one or more embodiments, with a small form factor and in accordance with wafer level packaging techniques or other packaging techniques.

In one embodiment, infrared imaging module **100** may be configured to be implemented in a small portable host device **102**, such as a mobile telephone, a tablet computing device, a laptop computing device, a personal digital assistant, a visible light camera, a music player, or any other appropriate mobile device. In this regard, infrared imaging module **100** may be used to provide infrared imaging features to host device **102**. For example, infrared imaging module **100** may be configured to capture, process, and/or otherwise manage infrared images and provide such infrared images to host device **102** for use in any desired fashion (e.g., for further processing, to store in memory, to display, to use by various applications running on host device **102**, to export to other devices, or other uses).

In various embodiments, infrared imaging module **100** may be configured to operate at low voltage levels and over a wide temperature range. For example, in one embodiment, infrared imaging module **100** may operate using a power supply of approximately 2.4 volts, 2.5 volts, 2.8 volts, or lower voltages, and operate over a temperature range of approximately −20 degrees C. to approximately +60 degrees C. (e.g., providing a suitable dynamic range and performance over an environmental temperature range of approximately 80 degrees C.). In one embodiment, by operating infrared imaging module **100** at low voltage levels, infrared imaging module **100** may experience reduced amounts of self heating in comparison with other types of infrared imaging devices. As a result, infrared imaging module **100** may be operated with reduced measures to compensate for such self heating.

As shown in FIG. **1**, host device **102** may include a socket **104**, a shutter **105**, motion sensors **194**, a processor **195**, a memory **196**, a display **197**, and/or other components **198**. Socket **104** may be configured to receive infrared imaging module **100** as identified by arrow **101**. In this regard, FIG. **2** illustrates infrared imaging module **100** assembled in socket **104** in accordance with an embodiment of the disclosure.

Motion sensors **194** may be implemented by one or more accelerometers, gyroscopes, or other appropriate devices that may be used to detect movement of host device **102**. Motion sensors **194** may be monitored by and provide information to processing module **160** or processor **195** to detect motion. In various embodiments, motion sensors **194** may be implemented as part of host device **102** (as shown in FIG. **1**), infrared imaging module **100**, or other devices attached to or otherwise interfaced with host device **102**.

Processor **195** may be implemented as any appropriate processing device (e.g., logic device, microcontroller, processor, application specific integrated circuit (ASIC), or other device) that may be used by host device **102** to execute appropriate instructions, such as software instructions provided in memory **196**. Display **197** may be used to display captured and/or processed infrared images and/or other images, data, and information. Other components **198** may be used to implement any features of host device **102** as may be desired for various applications (e.g., clocks, temperature sensors, a visible light camera, or other components). In addition, a machine readable medium **193** may be provided for storing non-transitory instructions for loading into memory **196** and execution by processor **195**.

In various embodiments, infrared imaging module **100** and socket **104** may be implemented for mass production to facilitate high volume applications, such as for implementation in mobile telephones or other devices (e.g., requiring small form factors). In one embodiment, the combination of infrared imaging module **100** and socket **104** may exhibit overall dimensions of approximately 8.5 mm by 8.5 mm by 5.9 mm while infrared imaging module **100** is installed in socket **104**.

FIG. **3** illustrates an exploded view of infrared imaging module **100** juxtaposed over socket **104** in accordance with an embodiment of the disclosure. Infrared imaging module **100** may include a lens barrel **110**, a housing **120**, an infrared sensor assembly **128**, a circuit board **170**, a base **150**, and a processing module **160**.

Lens barrel **110** may at least partially enclose an optical element **180** (e.g., a lens) which is partially visible in FIG. **3** through an aperture **112** in lens barrel **110**. Lens barrel **110** may include a substantially cylindrical extension **114** which may be used to interface lens barrel **110** with an aperture **122** in housing **120**.

Infrared sensor assembly **128** may be implemented, for example, with a cap **130** (e.g., a lid) mounted on a substrate **140**. Infrared sensor assembly **128** may include a plurality of infrared sensors **132** (e.g., infrared detectors) implemented in an array or other fashion on substrate **140** and covered by cap **130**. For example, in one embodiment, infrared sensor assembly **128** may be implemented as a focal plane array (FPA). Such a focal plane array may be implemented, for example, as a vacuum package assembly (e.g., sealed by cap **130** and substrate **140**). In one embodiment, infrared sensor assembly **128** may be implemented as a wafer level package (e.g., infrared sensor assembly **128** may be singulated from a set of vacuum package assemblies provided on a wafer). In one embodiment, infrared sensor assembly **128** may be implemented to operate using a power supply of approximately 2.4 volts, 2.5 volts, 2.8 volts, or similar voltages.

Infrared sensors **132** may be configured to detect infrared radiation (e.g., infrared energy) from a target scene including, for example, mid wave infrared wave bands (MWIR), long wave infrared wave bands (LWIR), and/or other thermal imaging bands as may be desired in particular implementations. In one embodiment, infrared sensor assembly **128** may be provided in accordance with wafer level packaging techniques.

Infrared sensors **132** may be implemented, for example, as microbolometers or other types of thermal imaging infrared sensors arranged in any desired array pattern to provide a plurality of pixels. In one embodiment, infrared sensors **132** may be implemented as vanadium oxide (VOx) detectors with a 17 μm pixel pitch. In various embodiments, arrays of approximately 32 by 32 infrared sensors **132**, approximately 64 by 64 infrared sensors **132**, approximately 80 by 64 infrared sensors **132**, or other array sizes may be used.

Substrate **140** may include various circuitry including, for example, a read out integrated circuit (ROIC) with dimensions less than approximately 5.5 mm by 5.5 mm in one embodiment. Substrate **140** may also include bond pads **142** that may be used to contact complementary connections positioned on inside surfaces of housing **120** when infrared imaging module **100** is assembled as shown in FIGS. **5**A, **5**B, and **5**C. In one embodiment, the ROIC may be implemented with low-dropout regulators (LDO) to perform voltage regulation to reduce power supply noise introduced to infrared sensor assembly **128** and thus provide an improved power supply rejection ratio (PSRR). Moreover, by implementing the LDO with the ROIC (e.g., within a wafer level package), less die area may be consumed and fewer discrete die (or chips) are needed.

FIG. **4** illustrates a block diagram of infrared sensor assembly **128** including an array of infrared sensors **132** in accordance with an embodiment of the disclosure. In the illustrated embodiment, infrared sensors **132** are provided as part of a unit cell array of a ROIC **402**. ROIC **402** includes bias generation and timing control circuitry **404**, column amplifiers **405**, a column multiplexer **406**, a row multiplexer **408**, and an output amplifier **410**. Image frames (e.g., thermal images) captured by infrared sensors **132** may be provided by output amplifier **410** to processing module **160**, processor **195**, and/or any other appropriate components to perform various processing techniques described herein. Although an 8 by 8 array is shown in FIG. **4**, any desired array configuration may be used in other embodiments. Further descriptions of ROICs and infrared sensors (e.g., microbolometer circuits) may be found in U.S. Pat. No. 6,028,309 issued Feb. 22, 2000, which is incorporated herein by reference in its entirety.

Infrared sensor assembly **128** may capture images (e.g., image frames) and provide such images from its ROIC at various rates. Processing module **160** may be used to perform appropriate processing of captured infrared images and may be implemented in accordance with any appropriate architecture. In one embodiment, processing module **160** may be implemented as an ASIC. In this regard, such an ASIC may be configured to perform image processing with high performance and/or high efficiency. In another embodiment, processing module **160** may be implemented with a general purpose central processing unit (CPU) which may be configured to execute appropriate software instructions to perform image processing, coordinate and perform image processing with various image processing blocks, coordinate interfacing between processing module **160** and host device **102**, and/or other operations. In yet another embodiment, processing module **160** may be implemented with a field programmable gate array (FPGA). Processing module **160** may be implemented with other types of processing and/or logic circuits in other embodiments as would be understood by one skilled in the art.

In these and other embodiments, processing module **160** may also be implemented with other components where appropriate, such as, volatile memory, non-volatile memory, and/or one or more interfaces (e.g., infrared detector interfaces, inter-integrated circuit (I2C) interfaces, mobile industry processor interfaces (MIPI), joint test action group (JTAG) interfaces (e.g., IEEE 1149.1 standard test access port and boundary-scan architecture), and/or other interfaces).

In some embodiments, infrared imaging module **100** may further include one or more actuators **199** which may be used to adjust the focus of infrared image frames captured by infrared sensor assembly **128**. For example, actuators **199** may be used to move optical element **180**, infrared sensors **132**, and/or other components relative to each other to selectively focus and defocus infrared image frames in accordance with techniques described herein. Actuators **199** may be implemented in accordance with any type of motion-inducing apparatus or mechanism, and may positioned at any location within or external to infrared imaging module **100** as appropriate for different applications.

When infrared imaging module **100** is assembled, housing **120** may substantially enclose infrared sensor assembly **128**, base **150**, and processing module **160**. Housing **120** may facilitate connection of various components of infrared imaging module **100**. For example, in one embodiment, housing **120** may provide electrical connections **126** to connect various components as further described.

Electrical connections **126** (e.g., conductive electrical paths, traces, or other types of connections) may be electrically connected with bond pads **142** when infrared imaging module **100** is assembled. In various embodiments, electrical connections **126** may be embedded in housing **120**, provided on inside surfaces of housing **120**, and/or otherwise provided by housing **120**. Electrical connections **126** may terminate in connections **124** protruding from the bottom surface of housing **120** as shown in FIG. **3**. Connections **124** may connect with circuit board **170** when infrared imaging module **100** is assembled (e.g., housing **120** may rest atop circuit board **170** in various embodiments). Processing module **160** may be electrically connected with circuit board **170** through appropriate electrical connections. As a result, infrared sensor assembly **128** may be electrically connected with processing module **160** through, for example, conductive electrical paths provided by: bond pads **142**, complementary connections on inside surfaces of housing **120**, electrical connections **126** of housing **120**, connections **124**, and circuit board **170**. Advantageously, such an arrangement may be implemented without requiring wire bonds to be provided between infrared sensor assembly **128** and processing module **160**.

In various embodiments, electrical connections **126** in housing **120** may be made from any desired material (e.g., copper or any other appropriate conductive material). In one embodiment, electrical connections **126** may aid in dissipating heat from infrared imaging module **100**.

Other connections may be used in other embodiments. For example, in one embodiment, sensor assembly **128** may be attached to processing module **160** through a ceramic board that connects to sensor assembly **128** by wire bonds and to processing module **160** by a ball grid array (BGA). In another embodiment, sensor assembly **128** may be mounted directly on a rigid flexible board and electrically connected with wire bonds, and processing module **160** may be mounted and connected to the rigid flexible board with wire bonds or a BGA.

The various implementations of infrared imaging module **100** and host device **102** set forth herein are provided for purposes of example, rather than limitation. In this regard, any of the various techniques described herein may be applied to any infrared camera system, infrared imager, or other device for performing infrared/thermal imaging.

Substrate **140** of infrared sensor assembly **128** may be mounted on base **150**. In various embodiments, base **150** (e.g., a pedestal) may be made, for example, of copper formed by metal injection molding (MIM) and provided with a black oxide or nickel-coated finish. In various embodiments, base **150** may be made of any desired material, such as for example zinc, aluminum, or magnesium, as desired for a given application and may be formed by any desired applicable process, such as for example aluminum casting, MIM, or zinc rapid casting, as may be desired for particular applications. In various embodiments, base **150** may be implemented to provide structural support, various circuit paths, thermal heat sink properties, and other features where appropriate. In one embodiment, base **150** may be a multi-layer structure implemented at least in part using ceramic material.

In various embodiments, circuit board **170** may receive housing **120** and thus may physically support the various components of infrared imaging module **100**. In various embodiments, circuit board **170** may be implemented as a printed circuit board (e.g., an FR4 circuit board or other types of circuit boards), a rigid or flexible interconnect (e.g., tape or other type of interconnects), a flexible circuit substrate, a flexible plastic substrate, or other appropriate structures. In various embodiments, base **150** may be implemented with the various features and attributes described for circuit board **170**, and vice versa.

Socket **104** may include a cavity **106** configured to receive infrared imaging module **100** (e.g., as shown in the assembled view of FIG. **2**). Infrared imaging module **100** and/or socket **104** may include appropriate tabs, arms, pins, fasteners, or any other appropriate engagement members which may be used to secure infrared imaging module **100** to or within socket **104** using friction, tension, adhesion, and/or any other appropriate manner. Socket **104** may include engagement members **107** that may engage surfaces **109** of housing **120** when infrared imaging module **100** is inserted into a cavity **106** of socket **104**. Other types of engagement members may be used in other embodiments.

Infrared imaging module **100** may be electrically connected with socket **104** through appropriate electrical connections (e.g., contacts, pins, wires, or any other appropriate connections). For example, socket **104** may include electrical connections **108** which may contact corresponding electrical connections of infrared imaging module **100** (e.g., interconnect pads, contacts, or other electrical connections on side or bottom surfaces of circuit board **170**, bond pads **142** or other electrical connections on base **150**, or other connections). Electrical connections **108** may be made from any desired material (e.g., copper or any other appropriate conductive material). In one embodiment, electrical connections **108** may be mechanically biased to press against electrical connections of infrared imaging module **100** when infrared imaging module **100** is inserted into cavity **106** of socket **104**. In one embodiment, electrical connections **108** may at least partially secure infrared imaging module **100** in socket **104**. Other types of electrical connections may be used in other embodiments.

Socket **104** may be electrically connected with host device **102** through similar types of electrical connections. For example, in one embodiment, host device **102** may include electrical connections (e.g., soldered connections, snap-in connections, or other connections) that connect with electrical connections **108** passing through apertures **190**. In various embodiments, such electrical connections may be made to the sides and/or bottom of socket **104**.

Various components of infrared imaging module **100** may be implemented with flip chip technology which may be used to mount components directly to circuit boards without the additional clearances typically needed for wire bond connections. Flip chip connections may be used, as an example, to reduce the overall size of infrared imaging module **100** for use in compact small form factor applications. For example, in one embodiment, processing module **160** may be mounted to circuit board **170** using flip chip connections. For example, infrared imaging module **100** may be implemented with such flip chip configurations.

In various embodiments, infrared imaging module **100** and/or associated components may be implemented in accordance with various techniques (e.g., wafer level packaging techniques) as set forth in U.S. patent application Ser. No. 12/844,124 filed Jul. 27, 2010, and U.S. Provisional Patent Application No. 61/469,651 filed Mar. 30, 2011, which are incorporated herein by reference in their entirety. Furthermore, in accordance with one or more embodiments, infrared imaging module **100** and/or associated components may be implemented, calibrated, tested, and/or used in accordance with various techniques, such as for example as set forth in U.S. Pat. No. 7,470,902 issued Dec. 30, 2008, U.S. Pat. No. 6,028,309 issued Feb. 22, 2000, U.S. Pat. No. 6,812,465 issued Nov. 2, 2004, U.S. Pat. No. 7,034,301 issued Apr. 25, 2006, U.S. Pat. No. 7,679,048 issued Mar. 16, 2010, U.S. Pat. No. 7,470,904 issued Dec. 30, 2008, U.S. patent application Ser. No. 12/202,880 filed Sep. 2, 2008, and U.S. patent application Ser. No. 12/202,896 filed Sep. 2, 2008, which are incorporated herein by reference in their entirety.

Referring again to FIG. **1**, in various embodiments, host device **102** may include shutter **105**. In this regard, shutter **105** may be selectively positioned over socket **104** (e.g., as identified by arrows **103**) while infrared imaging module **100** is installed therein. In this regard, shutter **105** may be used, for example, to protect infrared imaging module **100** when not in use. Shutter **105** may also be used as a temperature reference as part of a calibration process (e.g., a NUC process or other calibration processes) for infrared imaging module **100** as would be understood by one skilled in the art.

In various embodiments, shutter **105** may be made from various materials such as, for example, polymers, glass, aluminum (e.g., painted or anodized) or other materials. In various embodiments, shutter **105** may include one or more coatings to selectively filter electromagnetic radiation and/or adjust various optical properties of shutter **105** (e.g., a uniform blackbody coating or a reflective gold coating).

In another embodiment, shutter **105** may be fixed in place to protect infrared imaging module **100** at all times. In this case, shutter **105** or a portion of shutter **105** may be made from appropriate materials (e.g., polymers or infrared transmitting materials such as silicon, germanium, zinc selenide, or chalcogenide glasses) that do not substantially filter desired infrared wavelengths. In another embodiment, a shutter may be implemented as part of infrared imaging module **100** (e.g., within or as part of a lens barrel or other components of infrared imaging module **100**), as would be understood by one skilled in the art.

Alternatively, in another embodiment, a shutter (e.g., shutter **105** or other type of external or internal shutter) need not be provided, but rather a NUC process or other type of calibration may be performed using shutterless techniques. In another embodiment, a NUC process or other type of calibration using shutterless techniques may be performed in combination with shutter-based techniques.

Infrared imaging module **100** and host device **102** may be implemented in accordance with any of the various techniques set forth in U.S. Provisional Patent Application No. 61/495,873 filed Jun. 10, 2011, U.S. Provisional Patent Application No. 61/495,879 filed Jun. 10, 2011, and U.S. Provisional Patent Application No. 61/495,888 filed Jun. 10, 2011, which are incorporated herein by reference in their entirety.

In various embodiments, the components of host device **102** and/or infrared imaging module **100** may be implemented as a local or distributed system with components in communication with each other over wired and/or wireless networks. Accordingly, the various operations identified in this disclosure may be performed by local and/or remote components as may be desired in particular implementations.

FIG. **5** illustrates a flow diagram of various operations to determine NUC terms in accordance with an embodiment of the disclosure. In some embodiments, the operations of FIG. **5** may be performed by processing module **160** or processor **195** (both also generally referred to as a processor) operating on image frames captured by infrared sensors **132**.

In block **505**, infrared sensors **132** begin capturing image frames of a scene. Typically, the scene will be the real world environment in which host device **102** is currently located. In this regard, shutter **105** (if optionally provided) may be opened to permit infrared imaging module to receive infrared radiation from the scene. Infrared sensors **132** may continue capturing image frames during all operations shown in FIG. **5**. In this regard, the continuously captured image frames may be used for various operations as further discussed. In one embodiment, the captured image frames may be temporally filtered (e.g., in accordance with the process of block **826** further described herein with regard to FIG. **8**) and be processed by other terms (e.g., factory gain terms **812**, factory offset terms **816**, previously determined NUC terms **817**, column FPN terms **820**, and row FPN terms **824** as further described herein with regard to FIG. **8**) before they are used in the operations shown in FIG. **5**.

In block **510**, a NUC process initiating event is detected. In one embodiment, the NUC process may be initiated in response to physical movement of host device **102**. Such movement may be detected, for example, by motion sensors **194** which may be polled by a processor. In one example, a user may move host device **102** in a particular manner, such as by intentionally waving host device **102** back and forth in an "erase" or "swipe" movement. In this regard, the user may move host device **102** in accordance with a predetermined speed and direction (velocity), such as in an up and down, side to side, or other pattern to initiate the NUC process. In this example, the use of such movements may permit the user to intuitively operate host device **102** to simulate the "erasing" of noise in captured image frames.

In another example, a NUC process may be initiated by host device **102** if motion exceeding a threshold value is exceeded (e.g., motion greater than expected for ordinary use). It is contemplated that any desired type of spatial translation of host device **102** may be used to initiate the NUC process.

In yet another example, a NUC process may be initiated by host device **102** if a minimum time has elapsed since a previously performed NUC process. In a further example, a NUC process may be initiated by host device **102** if infrared imaging module **100** has experienced a minimum temperature change since a previously performed NUC process. In a still further example, a NUC process may be continuously initiated and repeated.

In block **515**, after a NUC process initiating event is detected, it is determined whether the NUC process should actually be performed. In this regard, the NUC process may be selectively initiated based on whether one or more additional conditions are met. For example, in one embodiment, the NUC process may not be performed unless a minimum time has elapsed since a previously performed NUC process. In another embodiment, the NUC process may not be performed unless infrared imaging module **100** has experienced a minimum temperature change since a previously performed NUC process. Other criteria or conditions may be used in other embodiments. If appropriate criteria or conditions have been met, then the flow diagram continues to block **520**. Otherwise, the flow diagram returns to block **505**.

In the NUC process, blurred image frames may be used to determine NUC terms which may be applied to captured image frames to correct for FPN. As discussed, in one embodiment, the blurred image frames may be obtained by accumulating multiple image frames of a moving scene (e.g., captured while the scene and/or the thermal imager is in motion). In another embodiment, the blurred image frames may be obtained by defocusing an optical element or other component of the thermal imager.

Accordingly, in block **520** a choice of either approach is provided. If the motion-based approach is used, then the flow diagram continues to block **525**. If the defocus-based approach is used, then the flow diagram continues to block **530**.

Referring now to the motion-based approach, in block **525** motion is detected. For example, in one embodiment, motion may be detected based on the image frames captured by infrared sensors **132**. In this regard, an appropriate motion detection process (e.g., an image registration process, a frame-to-frame difference calculation, or other appropriate process) may be applied to captured image frames to determine whether motion is present (e.g., whether static or moving image frames have been captured). For example, in one embodiment, it can be determined whether pixels or regions around the pixels of consecutive image frames have changed more than a user defined amount (e.g., a percentage and/or threshold value). If at least a given percentage of pixels have changed by at least the user defined amount, then motion will be detected with sufficient certainty to proceed to block **535**.

In another embodiment, motion may be determined on a per pixel basis, wherein only pixels that exhibit significant changes are accumulated to provide the blurred image frame. For example, counters may be provided for each pixel and used to ensure that the same number of pixel values are accumulated for each pixel, or used to average the pixel values based on the number of pixel values actually accumulated for each pixel. Other types of image-based motion detection may be performed such as performing a Radon transform.

In another embodiment, motion may be detected based on data provided by motion sensors **194**. In one embodiment, such motion detection may include detecting whether host device **102** is moving along a relatively straight trajectory through space. For example, if host device **102** is moving along a relatively straight trajectory, then it is possible that certain objects appearing in the imaged scene may not be sufficiently blurred (e.g., objects in the scene that may be aligned with or moving substantially parallel to the straight trajectory). Thus, in such an embodiment, the motion detected by motion sensors **194** may be conditioned on host device **102** exhibiting, or not exhibiting, particular trajectories.

In yet another embodiment, both a motion detection process and motion sensors **194** may be used. Thus, using any of these various embodiments, a determination can be made as to whether or not each image frame was captured while at least a portion of the scene and host device **102** were in motion relative to each other (e.g., which may be caused by host device **102** moving relative to the scene, at least a portion of the scene moving relative to host device **102**, or both).

It is expected that the image frames for which motion was detected may exhibit some secondary blurring of the captured scene (e.g., blurred thermal image data associated with the scene) due to the thermal time constants of infrared sensors **132** (e.g., microbolometer thermal time constants) interacting with the scene movement.

In block **535**, image frames for which motion was detected are accumulated. For example, if motion is detected for a continuous series of image frames, then the image frames of the series may be accumulated. As another example, if motion is detected for only some image frames, then the non-moving image frames may be skipped and not included in the accumulation. Thus, a continuous or discontinuous set of image frames may be selected to be accumulated based on the detected motion.

In block **540**, the accumulated image frames are averaged to provide a blurred image frame. Because the accumulated image frames were captured during motion, it is expected that actual scene information will vary between the image frames and thus cause the scene information to be further blurred in the resulting blurred image frame (block **545**).

In contrast, FPN (e.g., caused by one or more components of infrared imaging module **100**) will remain fixed over at least short periods of time and over at least limited changes in scene irradiance during motion. As a result, image frames captured in close proximity in time and space during motion will suffer from identical or at least very similar FPN. Thus, although scene information may change in consecutive image frames, the FPN will stay essentially constant. By averaging, multiple image frames captured during motion will blur the scene information, but will not blur the FPN. As a result, FPN will remain more clearly defined in the blurred image frame provided in block **545** than the scene information.

In one embodiment, 32 or more image frames are accumulated and averaged in blocks **535** and **540**. However, any desired number of image frames may be used in other embodiments, but with generally decreasing correction accuracy as frame count is decreased.

Referring now to the defocus-based approach, in block **530**, a defocus operation may be performed to intentionally defocus the image frames captured by infrared sensors **132**. For example, in one embodiment, one or more actuators **199** may be used to adjust, move, or otherwise translate optical element **180**, infrared sensor assembly **128**, and/or other components of infrared imaging module **100** to cause infrared sensors **132** to capture a blurred (e.g., unfocused) image frame of the scene. Other non-actuator based techniques are also contemplated for intentionally defocusing infrared image frames such as, for example, manual (e.g., user-initiated) defocusing.

Although the scene may appear blurred in the image frame, FPN (e.g., caused by one or more components of infrared imaging module **100**) will remain unaffected by the defocusing operation. As a result, a blurred image frame of the scene will be provided (block **545**) with FPN remaining more clearly defined in the blurred image than the scene information.

In the above discussion, the defocus-based approach has been described with regard to a single captured image frame. In another embodiment, the defocus-based approach may include accumulating multiple image frames while the infrared imaging module **100** has been defocused and averaging the defocused image frames to remove the effects of temporal noise and provide a blurred image frame in block **545**.

Thus, it will be appreciated that a blurred image frame may be provided in block **545** by either the motion-based approach or the defocus-based approach. Because much of the scene information will be blurred by either motion, defocusing, or both, the blurred image frame may be effectively considered a low pass filtered version of the original captured image frames with respect to scene information.

In block **550**, the blurred image frame is processed to determine updated row and column FPN terms (e.g., if row and column FPN terms have not been previously determined then the updated row and column FPN terms may be new row and column FPN terms in the first iteration of block **550**). As used in this disclosure, the terms row and column may be used interchangeably depending on the orientation of infrared sensors **132** and/or other components of infrared imaging module **100**.

In one embodiment, block **550** includes determining a spatial FPN correction term for each row of the blurred image frame (e.g., each row may have its own spatial FPN correction term), and also determining a spatial FPN correction term for each column of the blurred image frame (e.g., each column may have its own spatial FPN correction term). Such processing may be used to reduce the spatial and slowly varying (1/f) row and column FPN inherent in thermal imagers caused by, for example, 1/f noise characteristics of amplifiers in ROIC **402** which may manifest as vertical and horizontal stripes in image frames.

Advantageously, by determining spatial row and column FPN terms using the blurred image frame, there will be a reduced risk of vertical and horizontal objects in the actual imaged scene from being mistaken for row and column noise (e.g., real scene content will be blurred while FPN remains unblurred).

In one embodiment, row and column FPN terms may be determined by considering differences between neighboring pixels of the blurred image frame. For example, FIG. **6** illustrates differences between neighboring pixels in accordance with an embodiment of the disclosure. Specifically, in FIG. **6** a pixel **610** is compared to its 8 nearest horizontal neighbors: d**0**-d**3** on one side and d**4**-d**7** on the other side. Differences between the neighbor pixels can be averaged to obtain an estimate of the offset error of the illustrated group of pixels. An offset error may be calculated for each pixel in a row or column and the average result may be used to correct the entire row or column.

To prevent real scene data from being interpreted as noise, upper and lower threshold values may be used (thPix and

−thPix). Pixel values falling outside these threshold values (pixels d1 and d4 in this example) are not used to obtain the offset error. In addition, the maximum amount of row and column FPN correction may be limited by these threshold values.

Further techniques for performing spatial row and column FPN correction processing are set forth in U.S. patent application Ser. No. 12/396,340 filed Mar. 2, 2009 which is incorporated herein by reference in its entirety.

Referring again to FIG. **5**, the updated row and column FPN terms determined in block **550** are stored (block **552**) and applied (block **555**) to the blurred image frame provided in block **545**. After these terms are applied, some of the spatial row and column FPN in the blurred image frame may be reduced. However, because such terms are applied generally to rows and columns, additional FPN may remain such as spatially uncorrelated FPN associated with pixel to pixel drift or other causes. Neighborhoods of spatially correlated FPN may also remain which may not be directly associated with individual rows and columns. Accordingly, further processing may be performed as discussed below to determine NUC terms.

In block **560**, local contrast values (e.g., edges or absolute values of gradients between adjacent or small groups of pixels) in the blurred image frame are determined. If scene information in the blurred image frame includes contrasting areas that have not been significantly blurred (e.g., high contrast edges in the original scene data), then such features may be identified by a contrast determination process in block **560**.

For example, local contrast values in the blurred image frame may be calculated, or any other desired type of edge detection process may be applied to identify certain pixels in the blurred image as being part of an area of local contrast. Pixels that are marked in this manner may be considered as containing excessive high spatial frequency scene information that would be interpreted as FPN (e.g., such regions may correspond to portions of the scene that have not been sufficiently blurred). As such, these pixels may be excluded from being used in the further determination of NUC terms. In one embodiment, such contrast detection processing may rely on a threshold that is higher than the expected contrast value associated with FPN (e.g., pixels exhibiting a contrast value higher than the threshold may be considered to be scene information, and those lower than the threshold may be considered to be exhibiting FPN).

In one embodiment, the contrast determination of block **560** may be performed on the blurred image frame after row and column FPN terms have been applied to the blurred image frame (e.g., as shown in FIG. **5**). In another embodiment, block **560** may be performed prior to block **550** to determine contrast before row and column FPN terms are determined (e.g., to prevent scene based contrast from contributing to the determination of such terms).

Following block **560**, it is expected that any high spatial frequency content remaining in the blurred image frame may be generally attributed to spatially uncorrelated FPN. In this regard, following block **560**, much of the other noise or actual desired scene based information has been removed or excluded from the blurred image frame due to: intentional blurring of the image frame (e.g., by motion or defocusing in blocks **520** through **545**), application of row and column FPN terms (block **555**), and contrast determination of (block **560**).

Thus, it can be expected that following block **560**, any remaining high spatial frequency content (e.g., exhibited as areas of contrast or differences in the blurred image frame) may be attributed to spatially uncorrelated FPN. Accordingly, in block **565**, the blurred image frame is high pass filtered. In one embodiment, this may include applying a high pass filter to extract the high spatial frequency content from the blurred image frame. In another embodiment, this may include applying a low pass filter to the blurred image frame and taking a difference between the low pass filtered image frame and the unfiltered blurred image frame to obtain the high spatial frequency content. In accordance with various embodiments of the present disclosure, a high pass filter may be implemented by calculating a mean difference between a sensor signal (e.g., a pixel value) and its neighbors.

In block **570**, a flat field correction process is performed on the high pass filtered blurred image frame to determine updated NUC terms (e.g., if a NUC process has not previously been performed then the updated NUC terms may be new NUC terms in the first iteration of block **570**).

For example, FIG. **7** illustrates a flat field correction technique **700** in accordance with an embodiment of the disclosure. In FIG. **7**, a NUC term may be determined for each pixel **710** of the blurred image frame using the values of its neighboring pixels **712** to **726**. For each pixel **710**, several gradients may be determined based on the absolute difference between the values of various adjacent pixels. For example, absolute value differences may be determined between: pixels **712** and **714** (a left to right diagonal gradient), pixels **716** and **718** (a top to bottom vertical gradient), pixels **720** and **722** (a right to left diagonal gradient), and pixels **724** and **726** (a left to right horizontal gradient).

These absolute differences may be summed to provide a summed gradient for pixel **710**. A weight value may be determined for pixel **710** that is inversely proportional to the summed gradient. This process may be performed for all pixels **710** of the blurred image frame until a weight value is provided for each pixel **710**. For areas with low gradients (e.g., areas that are blurry or have low contrast), the weight value will be close to one. Conversely, for areas with high gradients, the weight value will be zero or close to zero. The update to the NUC term as estimated by the high pass filter is multiplied with the weight value.

In one embodiment, the risk of introducing scene information into the NUC terms can be further reduced by applying some amount of temporal damping to the NUC term determination process. For example, a temporal damping factor λ between 0 and 1 may be chosen such that the new NUC term (NUC_{NEW}) stored is a weighted average of the old NUC term (NUC_{OLD}) and the estimated updated NUC term (NUC_{UPDATE}). In one embodiment, this can be expressed as $NUC_{NEW}=\lambda\cdot NUC_{OLD}+(1-\lambda)\cdot(NUC_{OLD}+NUC_{UPDATE})$.

Although the determination of NUC terms has been described with regard to gradients, local contrast values may be used instead where appropriate. Other techniques may also be used such as, for example, standard deviation calculations. Other types flat field correction processes may be performed to determine NUC terms including, for example, various processes identified in U.S. Pat. No. 6,028,309 issued Feb. 22, 2000, U.S. Pat. No. 6,812,465 issued Nov. 2, 2004, and U.S. patent application Ser. No. 12/114,865 filed May 5, 2008, which are incorporated herein by reference in their entirety.

Referring again to FIG. **5**, block **570** may include additional processing of the NUC terms. For example, in one embodiment, to preserve the scene signal mean, the sum of all NUC terms may be normalized to zero by subtracting the

NUC term mean from each NUC term. Also in block **570**, to avoid row and column noise from affecting the NUC terms, the mean value of each row and column may be subtracted from the NUC terms for each row and column. As a result, row and column FPN filters using the row and column FPN terms determined in block **550** may be better able to filter out row and column noise in further iterations (e.g., as further shown in FIG. **8**) after the NUC terms are applied to captured images (e.g., in block **580** further discussed herein). In this regard, the row and column FPN filters may in general use more data to calculate the per row and per column offset coefficients (e.g., row and column FPN terms) and may thus provide a more robust alternative for reducing spatially correlated FPN than the NUC terms which are based on high pass filtering to capture spatially uncorrelated noise.

In blocks **571**-**573**, additional high pass filtering and further determinations of updated NUC terms may be optionally performed to remove spatially correlated FPN with lower spatial frequency than previously removed by row and column FPN terms. In this regard, some variability in infrared sensors **132** or other components of infrared imaging module **100** may result in spatially correlated FPN noise that cannot be easily modeled as row or column noise. Such spatially correlated FPN may include, for example, window defects on a sensor package or a cluster of infrared sensors **132** that respond differently to irradiance than neighboring infrared sensors **132**. In one embodiment, such spatially correlated FPN may be mitigated with an offset correction. If the amount of such spatially correlated FPN is significant, then the noise may also be detectable in the blurred image frame. Since this type of noise may affect a neighborhood of pixels, a high pass filter with a small kernel may not detect the FPN in the neighborhood (e.g., all values used in high pass filter may be taken from the neighborhood of affected pixels and thus may be affected by the same offset error). For example, if the high pass filtering of block **565** is performed with a small kernel (e.g., considering only immediately adjacent pixels that fall within a neighborhood of pixels affected by spatially correlated FPN), then broadly distributed spatially correlated FPN may not be detected.

For example, FIG. **11** illustrates spatially correlated FPN in a neighborhood of pixels in accordance with an embodiment of the disclosure. As shown in a sample image frame **1100**, a neighborhood of pixels **1110** may exhibit spatially correlated FPN that is not precisely correlated to individual rows and columns and is distributed over a neighborhood of several pixels (e.g., a neighborhood of approximately 4 by 4 pixels in this example). Sample image frame **1100** also includes a set of pixels **1120** exhibiting substantially uniform response that are not used in filtering calculations, and a set of pixels **1130** that are used to estimate a low pass value for the neighborhood of pixels **1110**. In one embodiment, pixels **1130** may be a number of pixels divisible by two in order to facilitate efficient hardware or software calculations.

Referring again to FIG. **5**, in blocks **571**-**573**, additional high pass filtering and further determinations of updated NUC terms may be optionally performed to remove spatially correlated FPN such as exhibited by pixels **1110**. In block **571**, the updated NUC terms determined in block **570** are applied to the blurred image frame. Thus, at this time, the blurred image frame will have been initially corrected for spatially correlated FPN (e.g., by application of the updated row and column FPN terms in block **555**), and also initially corrected for spatially uncorrelated FPN (e.g., by application of the updated NUC terms applied in block **571**).

In block **572**, a further high pass filter is applied with a larger kernel than was used in block **565**, and further updated NUC terms may be determined in block **573**. For example, to detect the spatially correlated FPN present in pixels **1110**, the high pass filter applied in block **572** may include data from a sufficiently large enough neighborhood of pixels such that differences can be determined between unaffected pixels (e.g., pixels **1120**) and affected pixels (e.g., pixels **1110**). For example, a low pass filter with a large kernel can be used (e.g., an N by N kernel that is much greater than 3 by 3 pixels) and the results may be subtracted to perform appropriate high pass filtering.

In one embodiment, for computational efficiency, a sparse kernel may be used such that only a small number of neighboring pixels inside an N by N neighborhood are used. For any given high pass filter operation using distant neighbors (e.g., a large kernel), there is a risk of modeling actual (potentially blurred) scene information as spatially correlated FPN. Accordingly, in one embodiment, the temporal damping factor λ may be set close to 1 for updated NUC terms determined in block **573**.

In various embodiments, blocks **571**-**573** may be repeated (e.g., cascaded) to iteratively perform high pass filtering with increasing kernel sizes to provide further updated NUC terms further correct for spatially correlated FPN of desired neighborhood sizes. In one embodiment, the decision to perform such iterations may be determined by whether spatially correlated FPN has actually been removed by the updated NUC terms of the previous performance of blocks **571**-**573**.

After blocks **571**-**573** are finished, a decision is made regarding whether to apply the updated NUC terms to captured image frames (block **574**). For example, if an average of the absolute value of the NUC terms for the entire image frame is less than a minimum threshold value, or greater than a maximum threshold value, the NUC terms may be deemed spurious or unlikely to provide meaningful correction. Alternatively, thresholding criteria may be applied to individual pixels to determine which pixels receive updated NUC terms. In one embodiment, the threshold values may correspond to differences between the newly calculated NUC terms and previously calculated NUC terms. In another embodiment, the threshold values may be independent of previously calculated NUC terms. Other tests may be applied (e.g., spatial correlation tests) to determine whether the NUC terms should be applied.

If the NUC terms are deemed spurious or unlikely to provide meaningful correction, then the flow diagram returns to block **505**. Otherwise, the newly determined NUC terms are stored (block **575**) to replace previous NUC terms (e.g., determined by a previously performed iteration of FIG. **5**) and applied (block **580**) to captured image frames.

FIG. **8** illustrates various image processing techniques of FIG. **5** and other operations applied in an image processing pipeline **800** in accordance with an embodiment of the disclosure. In this regard, pipeline **800** identifies various operations of FIG. **5** in the context of an overall iterative image processing scheme for correcting image frames provided by infrared imaging module **100**. In some embodiments, pipeline **800** may be provided by processing module **160** or processor **195** (both also generally referred to as a processor) operating on image frames captured by infrared sensors **132**.

Image frames captured by infrared sensors **132** may be provided to a frame averager **804** that integrates multiple image frames to provide image frames **802** with an improved signal to noise ratio. Frame averager **804** may be effectively provided by infrared sensors **132**, ROIC **402**, and other components of infrared sensor assembly **128** that are implemented to support high image capture rates. For example, in one embodiment, infrared sensor assembly **128** may capture infrared image frames at a frame rate of 240 Hz (e.g., 240 images per second). In this embodiment, such a high frame rate may be implemented, for example, by operating infrared sensor assembly **128** at relatively low voltages (e.g., compatible with mobile telephone voltages) and by using a relatively small array of infrared sensors **132** (e.g., an array of 64 by 64 infrared sensors in one embodiment).

In one embodiment, such infrared image frames may be provided from infrared sensor assembly **128** to processing module **160** at a high frame rate (e.g., 240 Hz or other frame rates). In another embodiment, infrared sensor assembly **128** may integrate over longer time periods, or multiple time periods, to provide integrated (e.g., averaged) infrared image frames to processing module **160** at a lower frame rate (e.g., 30 Hz, 9 Hz, or other frame rates). Further information regarding implementations that may be used to provide high image capture rates may be found in U.S. Provisional Patent Application No. 61/495,879 previously referenced herein.

Image frames **802** proceed through pipeline **800** where they are adjusted by various terms, temporally filtered, used to determine the various adjustment terms, and gain compensated.

In blocks **810** and **814**, factory gain terms **812** and factory offset terms **816** are applied to image frames **802** to compensate for gain and offset differences, respectively, between the various infrared sensors **132** and/or other components of infrared imaging module **100** determined during manufacturing and testing.

In block **580**, NUC terms **817** are applied to image frames **802** to correct for FPN as discussed. In one embodiment, if NUC terms **817** have not yet been determined (e.g., before a NUC process has been initiated), then block **580** may not be performed or initialization values may be used for NUC terms **817** that result in no alteration to the image data (e.g., offsets for every pixel would be equal to zero).

In blocks **818** and **822**, column FPN terms **820** and row FPN terms **824**, respectively, are applied to image frames **802**. Column FPN terms **820** and row FPN terms **824** may be determined in accordance with block **550** as discussed. In one embodiment, if the column FPN terms **820** and row FPN terms **824** have not yet been determined (e.g., before a NUC process has been initiated), then blocks **818** and **822** may not be performed or initialization values may be used for the column FPN terms **820** and row FPN terms **824** that result in no alteration to the image data (e.g., offsets for every pixel would be equal to zero).

In block **826**, temporal filtering is performed on image frames **802** in accordance with a temporal noise reduction (TNR) process. FIG. **9** illustrates a TNR process in accordance with an embodiment of the disclosure. In FIG. **9**, a presently received image frame **802***a* and a previously temporally filtered image frame **802***b* are processed to determine a new temporally filtered image frame **802***e*. Image frames **802***a* and **802***b* include local neighborhoods of pixels **803***a* and **803***b* centered around pixels **805***a* and **805***b*, respectively. Neighborhoods **803***a* and **803***b* correspond to the same locations within image frames **802***a* and **802***b* and are subsets of the total pixels in image frames **802***a* and **802***b*. In the illustrated embodiment, neighborhoods **803***a* and **803***b* include areas of 5 by 5 pixels. Other neighborhood sizes may be used in other embodiments.

Differences between corresponding pixels of neighborhoods **803***a* and **803***b* are determined and averaged to provide an averaged delta value **805***c* for the location corresponding to pixels **805***a* and **805***b*. Averaged delta value **805***c* may be used to determine weight values in block **807** to be applied to pixels **805***a* and **805***b* of image frames **802***a* and **802***b*.

In one embodiment, as shown in graph **809**, the weight values determined in block **807** may be inversely proportional to averaged delta value **805***c* such that weight values drop rapidly towards zero when there are large differences between neighborhoods **803***a* and **803***b*. In this regard, large differences between neighborhoods **803***a* and **803***b* may indicate that changes have occurred within the scene (e.g., due to motion) and pixels **802***a* and **802***b* may be appropriately weighted, in one embodiment, to avoid introducing blur across frame-to-frame scene changes. Other associations between weight values and averaged delta value **805***c* may be used in various embodiments.

The weight values determined in block **807** may be applied to pixels **805***a* and **805***b* to determine a value for corresponding pixel **805***e* of image frame **802***e* (block **811**). In this regard, pixel **805***e* may have a value that is a weighted average (or other combination) of pixels **805***a* and **805***b*, depending on averaged delta value **805***c* and the weight values determined in block **807**.

For example, pixel **805***e* of temporally filtered image frame **802***e* may be a weighted sum of pixels **805***a* and **805***b* of image frames **802***a* and **802***b*. If the average difference between pixels **805***a* and **805***b* is due to noise, then it may be expected that the average change between neighborhoods **805***a* and **805***b* will be close to zero (e.g., corresponding to the average of uncorrelated changes). Under such circumstances, it may be expected that the sum of the differences between neighborhoods **805***a* and **805***b* will be close to zero. In this case, pixel **805***a* of image frame **802***a* may both be appropriately weighted so as to contribute to the value of pixel **805***e*.

However, if the sum of such differences is not zero (e.g., even differing from zero by a small amount in one embodiment), then the changes may be interpreted as being attributed to motion instead of noise. Thus, motion may be detected based on the average change exhibited by neighborhoods **805***a* and **805***b*. Under these circumstances, pixel **805***a* of image frame **802***a* may be weighted heavily, while pixel **805***b* of image frame **802***b* may be weighted lightly.

Other embodiments are also contemplated. For example, although averaged delta value **805***c* has been described as being determined based on neighborhoods **805***a* and **805***b*, in other embodiments averaged delta value **805***c* may be determined based on any desired criteria (e.g., based on individual pixels or other types of groups of sets of pixels).

In the above embodiments, image frame **802***a* has been described as a presently received image frame and image frame **802***b* has been described as a previously temporally filtered image frame. In another embodiment, image frames **802***a* and **802***b* may be first and second image frames captured by infrared imaging module **100** that have not been temporally filtered.

FIG. **10** illustrates further implementation details in relation to the TNR process of block **826**. As shown in FIG. **10**, image frames **802***a* and **802***b* may be read into line buffers **1010***a* and **1010***b*, respectively, and image frame **802***b* (e.g., the previous image frame) may be stored in a frame buffer **1020** before being read into line buffer **1010***b*. In one embodiment, line buffers **1010***a-b* and frame buffer **1020** may be implemented by a block of random access memory

(RAM) provided by any appropriate component of infrared imaging module **100** and/or host device **102**.

Referring again to FIG. **8**, image frame **802***e* may be passed to an automatic gain compensation block **828** for further processing to provide a result image frame **830** that may be used by host device **102** as desired.

FIG. **8** further illustrates various operations that may be performed to determine row and column FPN terms and NUC terms as discussed. In one embodiment, these operations may use image frames **802***e* as shown in FIG. **8**. Because image frames **802***e* have already been temporally filtered, at least some temporal noise may be removed and thus will not inadvertently affect the determination of row and column FPN terms **824** and **820** and NUC terms **817**. In another embodiment, non-temporally filtered image frames **802** may be used.

In FIG. **8**, blocks **510**, **515**, and **520** of FIG. **5** are collectively represented together. As discussed, a NUC process may be selectively initiated and performed in response to various NUC process initiating events and based on various criteria or conditions. As also discussed, the NUC process may be performed in accordance with a motion-based approach (blocks **525**, **535**, and **540**) or a defocus-based approach (block **530**) to provide a blurred image frame (block **545**). FIG. **8** further illustrates various additional blocks **550**, **552**, **555**, **560**, **565**, **570**, **571**, **572**, **573**, and **575** previously discussed with regard to FIG. **5**.

As shown in FIG. **8**, row and column FPN terms **824** and **820** and NUC terms **817** may be determined and applied in an iterative fashion such that updated terms are determined using image frames **802** to which previous terms have already been applied. As a result, the overall process of FIG. **8** may repeatedly update and apply such terms to continuously reduce the noise in image frames **830** to be used by host device **102**.

Referring again to FIG. **10**, further implementation details are illustrated for various blocks of FIGS. **5** and **8** in relation to pipeline **800**. For example, blocks **525**, **535**, and **540** are shown as operating at the normal frame rate of image frames **802** received by pipeline **800**. In the embodiment shown in FIG. **10**, the determination made in block **525** is represented as a decision diamond used to determine whether a given image frame **802** has sufficiently changed such that it may be considered an image frame that will enhance the blur if added to other image frames and is therefore accumulated (block **535** is represented by an arrow in this embodiment) and averaged (block **540**).

Also in FIG. **10**, the determination of column FPN terms **820** (block **550**) is shown as operating at an update rate that in this example is 1/32 of the sensor frame rate (e.g., normal frame rate) due to the averaging performed in block **540**. Other update rates may be used in other embodiments. Although only column FPN terms **820** are identified in FIG. **10**, row FPN terms **824** may be implemented in a similar fashion at the reduced frame rate.

FIG. **10** also illustrates further implementation details in relation to the NUC determination process of block **570**. In this regard, the blurred image frame may be read to a line buffer **1030** (e.g., implemented by a block of RAM provided by any appropriate component of infrared imaging module **100** and/or host device **102**). The flat field correction technique **700** of FIG. **7** may be performed on the blurred image frame.

In view of the present disclosure, it will be appreciated that techniques described herein may be used to remove various types of FPN (e.g., including very high amplitude FPN) such as spatially correlated row and column FPN and spatially uncorrelated FPN.

Other embodiments are also contemplated. For example, in one embodiment, the rate at which row and column FPN terms and/or NUC terms are updated can be inversely proportional to the estimated amount of blur in the blurred image frame and/or inversely proportional to the magnitude of local contrast values (e.g., determined in block **560**).

In various embodiments, the described techniques may provide advantages over conventional shutter-based noise correction techniques. For example, by using a shutterless process, a shutter (e.g., such as shutter **105**) need not be provided, thus permitting reductions in size, weight, cost, and mechanical complexity. Power and maximum voltage supplied to, or generated by, infrared imaging module **100** may also be reduced if a shutter does not need to be mechanically operated. Reliability will be improved by removing the shutter as a potential point of failure. A shutterless process also eliminates potential image interruption caused by the temporary blockage of the imaged scene by a shutter.

Also, by correcting for noise using intentionally blurred image frames captured from a real world scene (not a uniform scene provided by a shutter), noise correction may be performed on image frames that have irradiance levels similar to those of the actual scene desired to be imaged. This can improve the accuracy and effectiveness of noise correction terms determined in accordance with the various described techniques.

Referring now to FIG. **12**, a block diagram is shown of a monitor and control system **1200** for enhancing occupant safety and energy efficiency in accordance with an embodiment of the disclosure. System **1200** may include one or more infrared imaging modules **1202**, a processor **1204**, a memory **1206**, a display **1208**, a control module **1210**, a communication module **1212**, a power module **1214**, a mode sensing module **1216**, and/or motion sensors **1218**. In various embodiments, system **1200** may include one or more other components **1220**, which may include various types of sensors such as a humidity sensor, a water level sensor, a gaseous fume sensor, etc. In various embodiments, the various components of system **1200** may be implemented in the same or similar manner as corresponding components of host device **102** of FIG. **1**. Moreover, the various components of system **1200** may be configured to perform various NUC processes and other processes described herein.

Infrared imaging module **1202** may be a small form factor infrared camera or a small form factor infrared imaging device implemented in accordance with various embodiments disclosed herein. Infrared imaging module **1202** may be configured to capture, process, and/or otherwise manage infrared images (e.g., including thermal images) of a scene **1230**, and provide such images to processor **1204**. Infrared imaging module **1202** may include an FPA implemented, for example, in accordance with various embodiments disclosed herein or others where appropriate.

Optionally, infrared imaging module **1202** may include one or more filters **1203** that may be adapted to pass infrared radiation of certain wavelengths (e.g., short-wave infrared (SWIR) filter, mid-wave infrared (MWIR) filter, long-wave infrared (LWIR) filter). Filters **1203** may be utilized to tailor infrared imaging module **1202** for increased sensitivity to a desired range of infrared wavelengths. For example, when used to detect a gas leak as further described herein, infrared imaging module **1202** may be better suited to detect a certain type of gas by using an appropriate filter. In some embodiments, filters **1203** may be selectable (e.g., a selectable filter wheel). In other embodiments, filters **1203** may be fixed as appropriate for a desired usage of infrared imaging module **1202**.

Processor **1204** may be implemented as any appropriate processing device as described with regard to processor **195** in FIG. **1**. Processor **1204** may be adapted to interface and communicate with other components of system **1200** to perform methods and processes described herein. Processor **1204** may include one or more submodules **1205** for operating in one or more modes of operation, wherein submodules **1205** may be adapted to define preset processing, displaying, and/or controlling functions that may be embedded in processor **1204** or stored on memory **1206** for access and execution by processor **1204**. For example, processor **1204** may be adapted to perform various processes for detecting the presence of hazardous chemicals or conditions, such as a natural gas leak, carbon monoxide (CO), volatile organic compound, fire, smoke, etc., and generating appropriate control signals and/or alarms. In another example, processor **1204** may be adapted to perform various processes for monitoring and controlling energy usage in an area. In yet another example, processor **1204** may be adapted to perform various processes for monitoring and reporting persons in need of assistance. In yet another example, processor **1204** may be adapted to perform various processes for detecting intruders. In various embodiments, processor **1204** may be adapted to perform various types of image processing algorithms and/or various modes of operation, as described herein.

It should be appreciated that each of the submodules **1205** may be integrated in software and/or hardware as part of processor **1204**, or code (e.g., software or configuration data) for each mode of operation associated with each of the submodules **1205** may be stored in memory component **1206**. Embodiments of submodules **1205** (i.e., modes of operation) disclosed herein may be stored by a separate computer-readable medium (e.g., a non-transitory memory, such as a hard drive, a compact disk, a digital video disk, or a flash memory) to be executed by a computer (e.g., logic or processor-based system) to perform various methods disclosed herein. In one example, the computer-readable medium may be portable and/or located separate from system **1200**, with stored submodules **1205** provided to system **1200** by coupling the computer-readable medium to system **1200** and/or by system **1200** downloading (e.g., via a wired or wireless link) submodules **1205** from the computer-readable medium (e.g., containing the non-transitory information).

In various embodiments, submodules **1205** may be utilized by system **1200** to perform one or more different modes of operation. System **1200** may operate in many different modes simultaneously, for example by performing many modes of operation in parallel, through multitasking, or otherwise in a current manner. The modes of operation are described in greater detail herein. In various embodiments, as described herein, submodules **1205** provide for improved thermal image processing techniques for real time applications associated with different modes of operation, such as the power usage monitoring and control mode of operation, the hazardous condition monitoring mode of operation, the energy efficiency monitoring mode of operation, the rescue assistance mode of operation, the intruder detection mode of operation, and other modes of operation that may be supported by system **1200**.

Memory **1206** may include one or more memory devices to store data and information, including thermal image data and information and thermal video image data and information. The one or more memory devices may include various types of memory for thermal image and video image storage including volatile and non-volatile memory devices, such as RAM (Random Access Memory), ROM (Read-Only Memory), EEPROM (Electrically-Erasable Read-Only Memory), flash memory, etc. In one embodiment, processor **1204** is adapted to execute software stored on memory component **1206** to perform various methods, processes, and modes of operations in manner as described herein.

Display **1208** may include an image display device (e.g., a liquid crystal display (LCD)) or various other types of generally known video displays or monitors. Processor **1204** may be adapted to display image data and information on display **1208**. Processor **1204** may be adapted to retrieve image data and information from memory **1206** and display any retrieved image data and information on display **1208**. Display **1208** may include display logic, which may be utilized by processor **1204** to display image data and information (e.g., captured and/or processed thermal images). Display **1208** may receive image data and information directly from infrared imaging modules **1202** via processor **1204**, or the image data and information may be transferred from memory **1206** via processor **1204**.

In one embodiment, processor **1204** may initially process a captured image in one or more modes, corresponding to submodules **1205**. The processed image may be used by the processor **1204** to determine the appropriate action to take for the different modes of operations. In one embodiment, the processed image for one mode may be presented to display **1208** for viewing. Upon user input to control module **1210**, processor **1204** may present the processed image for a different mode to display **1208** for viewing. In various aspects, display **1208** may be remotely positioned, and processor **1204** may be adapted to remotely display image data and information on display **1208** via wired or wireless communication with display **1208**.

Control module **1210** may include a user input and/or interface device having one or more user actuated components. For example, actuated components may include one or more push buttons, slide bars, rotatable knobs, and/or a keyboard, that are adapted to generate one or more user actuated input control signals. Control module **1210** may be adapted to be integrated as part of display **1208** to function as both a user input device and a display device. For example, control module **1210** may include a graphical user interface (GUI), which may be integrated as part of display **1208** (e.g., a user actuated touch screen), having one or more images of the user-activated mechanisms (e.g., buttons, knobs, sliders, etc.), which are adapted to interface with a user and receive user input control signals via display **1208**. Processor **1204** may be adapted to sense control input signals from control module **1210** and respond to any sensed control input signals received therefrom.

Control module **1210** may include, in one embodiment, a control panel unit (e.g., a wired or wireless handheld control unit) having one or more user-activated mechanisms (e.g., buttons, knobs, sliders, etc.) adapted to interface with a user and receive user input control signals. In various embodiments, the user-activated mechanisms of the control panel unit, as well as the user-activated mechanisms of the GUI, may be utilized to select one or more modes of operation, as described herein in reference to submodules **1205**. In addition, the user-activated mechanisms may be utilized to control and set various parameters of the selected modes of operation, such as detection targets (e.g., type of gas leak to detect), detection sensitivity (e.g., number of persons and duration of stay to trigger power-saving operations), devices to control, desired temperature settings, etc. In other embodiments, it should be appreciated that the control panel unit may be adapted to include one or more other user-activated mechanisms to provide various other control functions of system **1200**, such as auto-focus, menu enable and selection, field of view (FOV), brightness, contrast, gain, offset, spatial, temporal, and/or various other features and/or parameters. In still other embodiments, a variable gain signal may be adjusted by the user or operator based on a selected mode of operation.

Communication module **1212** may include a network interface component (NIC) adapted for wired and/or wireless communication with a network and with other devices connected to the network. Through communication module **1212**, processor **1204** may control power or operation of devices (e.g., heaters, air conditioning units, lamps, kitchen appliances, etc.) connected to the network. In this regard, communication module **1212** may support various interfaces, protocols, and standards for home and building automation networking, such as the X10 standard, the Building Automation and Control Networks (BACNet) protocol, the S-Bus protocol, the C-bus protocol, the CEBus protocol, the ONE-NET standard, etc. Control signals to devices may be transmitted from communication module **1212** directly to devices using such standards, or may be transmitted to a central controller (e.g., a conventional building control panel for centrally controlling and monitoring HVAC, lighting, power, water, and/or building access) that relays and distributes the control signals to various devices under its control.

In some embodiments, communication module **1212** may provide a proprietary interface and/or protocol for controlling power and/or operation of various devices. Such a proprietary interface and/or protocol may be based on the various types of wired and wireless networking technology supported by communication module **1212** as described below.

In various embodiments, communication module **1212** may include a wireless communication component, such as a wireless local area network (WLAN) component based on the IEEE 802.11 standards, a wireless broadband component, mobile cellular component, a wireless satellite component, or various other types of wireless communication components including radio frequency (RF), microwave frequency (MWF), and/or infrared frequency (IRF) components, such as wireless transceivers, adapted for communication with a wired and/or wireless network. As such, communication module **1212** may include an antenna coupled thereto for wireless communication purposes. In other embodiments, the communication module **1212** may be adapted to interface with a wired network via a wired communication component, such as a DSL (e.g., Digital Subscriber Line) modem, a PSTN (Public Switched Telephone Network) modem, an Ethernet device, a cable modem, a power-line modem, etc. for interfacing with DSL, Ethernet, cable, optical-fiber, power-line and/or various other types wired networks and for communication with other devices on the wired network. Communication module **1212** may be adapted to transmit and/or receive one or more wired and/or wireless video feeds.

In various embodiments, the network may be implemented as a single network or a combination of multiple networks. For example, in various embodiments, the network may include the Internet and/or one or more intranets, landline networks, wireless networks, and/or other appropriate types of communication networks. In another example, the network may include a wireless telecommunications network (e.g., cellular phone network) adapted to communicate with other communication networks, such as the Internet. As such, in various embodiments, system **1200** may be associated with a particular network link such as for example a URL (Uniform Resource Locator), an IP (Internet Protocol) address, and/or a mobile phone number.

Power module **1214** comprises a power supply or power source adapted to provide power to system **1200** including each component of system **1200**. Power module **1214** may comprise various types of power storage devices, such as battery, or a power interface component that is adapted to receive external power and convert the received external power to a useable power for system **1200**.

Mode sensing module **1216** may be optional. Mode sensing module **1216** may include, in one embodiment, an application sensor adapted to automatically sense a mode of operation, depending on the sensed application (e.g., intended use for an embodiment), and provide related information to processor **1204**. In various embodiments, the application sensor may include a mechanical triggering mechanism (e.g., a clamp, clip, hook, switch, push-button, etc.), an electronic triggering mechanism (e.g., an electronic switch, push-button, electrical signal, electrical connection, etc.), an electro-mechanical triggering mechanism, an electro-magnetic triggering mechanism, or some combination thereof. For example, mode sensing module **1216** may sense a mode of operation corresponding to the intended application of the infrared imaging system **100** based on the type of mount (e.g., accessory or fixture) to which a user has coupled system **1200** or one or more of its components (e.g., infrared imaging module **1202**). In such embodiments, mode sensing module **1216** may, for example, sense that system **1200** is intended for the power usage monitoring and control mode of operation by sensing that infrared imaging module **1202** is mounted in a conference room. The mode of operation may also be provided via control module **1210** by a user of system **1200**, in one or more embodiments. For example, a user may put system **1200** in an intruder detection mode of operation at night or when leaving, through actuated components and/or GUI of control module **1210**. In this regard, control module **1210** may be configured to permit a user to set a timer for activating certain modes of operation (e.g., intruder detection mode) at certain times (e.g., at night, weekends, or when vacating premises).

Mode sensing module **1216**, in one embodiment, may include a mechanical locking mechanism adapted to secure system **1200** to a structure or part thereof and may include a sensor adapted to provide a sensing signal to processor **1204** when system **1200** is mounted and/or secured to the structure. Mode sensing module **1216**, in one embodiment, may be adapted to receive an electrical signal and/or sense an electrical connection type and/or mount type and provide a sensing signal to processor **1204**.

In various embodiments, mode sensing module **1216** may be adapted to provide data and information relating to various system applications including various coupling implementations associated with various types of structures (e.g., buildings, bridges, tunnels, vehicles, etc.). In various embodiments, mode sensing module **1216** may include communication devices that relay data and information to processor **1204** via wired and/or wireless communication. For example, mode sensing module **1216** may be adapted to receive and/or provide information through a satellite, through a local broadcast transmission (e.g., radio frequency), through a mobile or cellular network, and/or through information beacons in an infrastructure (e.g., a transportation or highway information beacon infrastructure) or various other wired and/or wireless techniques. Thus, for example, mode sensing module **1216** may receive a notification of an emergency through various networks, and relay the notification to processor **1204** so that system **1200** may operate in a rescue assistance mode (e.g., monitoring and reporting of persons in need of assistance) in case of an emergency.

Motion sensors **1218** may be implemented in the same or similar manner as described with regard to motion sensors **194** in FIG. **1**. Motion sensors **1218** may be monitored by and provide information to infrared imaging module **1202** and/or processor **1204** for performing various NUC techniques described herein.

In various embodiments, one or more components of system **1200** may be combined and/or implemented or not, as desired or depending on application requirements, with system **1200** representing various functional blocks of a system. For example, processor **1204** may be combined with infrared imaging module **1202**, memory **1206**, display component **1208**, and/or mode sensing module **1216**. In another example, processor **1204** may be combined with infrared imaging sensor **1202** with only certain functions of processor **1203** performed by circuitry (e.g., processor, logic device, microprocessor, microcontroller, etc.) within infrared imaging module **1202**. In still another example, control module **1210** may be combined with one or more other components or be remotely connected to at least one other component, such as processor **1204**, via a wired or wireless control device so as to provide control signals thereto.

System **1200** may include a permanently mounted infrared imaging module **1202** coupled, for example, to various types of structures (e.g., buildings bridges, tunnels, etc.). System **1200** may include a portable infrared imaging module and may be implemented, for example, as a handheld device and/or coupled, in other examples, to various types of vehicles (e.g., land-based vehicles, watercraft, aircraft, spacecraft, etc.) or structures via one or more types of mounts.

During normal operation, system **1200** may be adapted to analyze infrared radiation captured by infrared imaging modules **1202** to detect heat source such as a person, an appliance in use, a fire, or to detect gas, carbon monoxide, or other chemicals in the area being monitored. The infrared imaging system **1200** may also provide a live video feed of thermal images captured with infrared imaging modules **1202** through a wired cable link or wireless communication link. Captured video images may be utilized for surveillance operations. In one embodiment, radiometric calibration allows the system **1200** to detect for the presence and the number of objects in image **1230** (e.g., persons **1232**, appliances **1234** and **1236**) emitting heat in particular temperature ranges. In one embodiment, system **1200** may analyze the spectral content and intensity pattern of infrared emission to detect gas, or other chemicals that may a pose a hazard.

In one embodiment, processor **1204** utilizes one or more submodules **1205** configured as a person detection submodule to determine or provide awareness of whether one or more persons are present in scene **1230**, such as persons **1232**. If at least one person is present, then system **1200** may be adapted to determine the number of persons and to control lighting (e.g., a lamp **1234**), HVAC system (e.g., a heater/AC unit **1236**) in the area being monitored. The control for the lighting, HVAC system may be transmitted through communication module **1212** to a network.

In one embodiment, processor **1204** utilizes one or more submodules **1205** configured as a person detection submodule to determine whether one or more persons are present in scene **1230**, such as persons **1232**. If at least one person is present, then processor **1204** may further determine whether the person or persons may need assistance. The determination may be based at least on the person's posture (e.g., standing up or fallen down), and may also be based on other attributes such as the body temperature and/or the duration for which the person remained motionless. In an event of an emergency (e.g., earthquake, fire, and other disasters), processor **1204** may transmit information including the location of detected persons and whether the persons may need of assistance. Such information may be transmitted through communication module **1212** to a network, so that emergency responders may access the information to locate rescuees and plan a rescue operation (e.g., prioritize rescuees based on the indication of whether they may need assistance).

FIGS. **13**A-**13**D illustrate various views of various building-mountable monitoring and controlling systems **1300**A and **1300**B for enhancing occupant safety and energy efficiency in accordance with various embodiments of the disclosure. More specifically, FIG. **13**A-**13**B are a side schematic view and a bottom schematic view, respectively, of system **1300**A having a ceiling-mountable portion, and FIG. **13**C-**13**D are a perspective schematic view and a front schematic view, respectively, of system **1300**B having a wall-mountable portion.

System **1300**A/**1300**B may include one or more infrared imaging modules **1302**, a processor **1304**, a memory **1306**, a display **1308**, a control module **1310**, a communication module **1312**, a power module **1314**, and/or a mode sensing module **1316**, and/or motion sensors **1318**, all of which may be implemented in the same or similar manner as the corresponding components of system **1200** of FIG. **12**.

System **1300**A may comprise an enclosure **1301**A that houses at least one infrared imaging module **1302**, and may optionally house other components of system **1300**A. Enclosure **1301**A can be mounted, attached, or otherwise coupled to a ceiling **1340** via a set of suitable fasteners **1344** (e.g., screws, bolts, hooks, etc.), so that infrared imaging module looks down on the objects (e.g., persons **1332**, lighting equipment **1334**, an HVAC unit **1336**) in the space below (e.g., a room). In this regard, infrared imaging module **1302** may be coupled to a lens unit **1303** having a wide field of view (FOV), including a fish-eye lens or omni-directional lens, that helps to expand the area covered by infrared imaging module **1302**. Enclosure **1301**A may further comprise a lens shield **1346**A adapted to pass infrared radiation through to infrared imaging module **1302**, which may be shaped as a dome, hemisphere, fish-eye, or other shape suitable for use with a wide FOV. For example, lens shield **1346**A may be implemented using an infrared-transmissive dome disclosed in commonly assigned U.S. patent application Ser. No. 12/721,870, filed Mar. 11, 2010, the entire content of which is incorporated herein by reference.

Similarly, system **1300**B may comprise an enclosure **1301**B that houses at least one infrared imaging module **1302** and optionally other components of system **1300**B. Enclosure **1301**B can be mounted, attached, or otherwise coupled to a wall **1342** via a set of suitable fasteners **1344**. Similar to lens shield **1346**A, lens shield **1346**B is adapted to pass infrared radiation through to infrared imaging module **1302** and shaped suitably to use with a wide FOV. For example, lens shield **1346**B may be constructed using methods disclosed in commonly assigned U.S. patent application Ser. No. 12/721,870 referenced above.

In one embodiment, display **1308** may be separate from enclosure **1301**A/**1301**B, and communicatively coupled to communication module **1312** via wired link **1348** or wireless link. Display may optionally include control module **1310** with a control panel similar to control module **1210** described above in connection with FIG. **12**. In another embodiment, a conventional building control panel (e.g., control panel for centrally controlling and monitoring HVAC, lighting, power, and/or building access status) well-known in the art of building automation may provide some of the functionality of a display and a control module. System **1301**A/**1301**B may communicate with such a building control panel via communication module **1312** and wired or wireless link.

System **1300**A/**1300**B may use a battery (e.g., a lithium battery) and, therefore, not require an external power source. Alternately, system **1300**A/**1300**B may draw power via wire **1349** from the power wiring already embedded in a building.

It should be appreciated that all or part of system **1200**/**1300**A/**1300**B may be fixedly or removably attached or mounted to any other component (e.g., beams, doors, pillars) of various types of structures (e.g., buildings, bridges, garages) and vehicles, as discussed above with respect to FIG. **12**. It should also be appreciated that system **1200**/**1300**A/**1300**B may be implemented as a networked system of sensors, as described in further detail with respect to FIG. **14**.

FIG. **14** illustrates a schematic view of a networked system **1400** for monitoring and controlling of a structure **1430** to enhance occupant safety and energy efficiency in accordance with various embodiments of the disclosure. Various components of networked system **1400** may be implemented in a similar or same manner as the corresponding components of system **1200**/**1300**A/**1300**B.

As shown, in one or more embodiments, networked system **1400** utilizes a plurality of various monitoring devices **1450**, which may include the wall-mountable or ceiling-mountable portions of system **1300**A and **1300**B. Monitoring devices **1450** may be attached to a wall, ceiling, baseboard, cabinet, or anywhere a wide field of view of a desired area may be achieved. Each monitoring device **1450** has at least one infrared imaging module that can capture a thermal image of the scene covered by its FOV.

In one embodiment, networked system **1400** also includes a base unit **1452** that functions as a receiver/processor for all monitoring devices **1450**. In this regard, base unit **1452** may comprise at least a processor **1404** and a communication module **1412**. Base unit **1452** may be adapted to record data, process data, and transmit data (e.g., in real time) to a hosted website for remote viewing and retrieval by a user, for example, by emergency responders to access information including the location of all persons remaining in premises and whether they may be in need of assistance. Each monitoring device **1450** communicates with base unit **1452** and/or with each other via a wired link **1448** or a wireless link.

Base unit **1452** may control power or operation of power-consuming devices **1434** (e.g., heaters, air conditioners, lighting equipment, kitchen appliances, TV, audio equipment, etc.) connected to it via network to provide a more energy efficient operation of such devices, as further described herein. As described above with respect to communication module **1212** of FIG. **12**, base unit **1452** may communicate with devices **1434** via various standardized interfaces and protocols, or it may utilize a proprietary interface and protocols.

Base unit **1452** may also be configured to sound one or more alarms **1458** connected to it via network, in case a hazardous condition is detected using processes further described herein. For example, monitoring devices **1450** may be distributed throughout structure **1430** to detect fire, gas leak, CO, and/or flood. If such hazardous conditions are detected, networked system **1400** provides an alarm (e.g., activating alarms **1458**, an email alert, a text message, and/or any other desired form of communication for a desired warning) to warn occupants and notify appropriate personnel (e.g., the fire department).

Base unit **1452** may further include a display **1408** and a control module **1410** with a control panel **1411** that allow users to view real time readings on site and toggle between monitoring devices in different locations of structure **1430**. Display **1408** may comprise a touch-sensitive screen for improved usability. As described in connection with display **1208** and control module **1210** of FIG. **12**, display **1408** and control panel **1411** may include various user-activated mechanisms (e.g., buttons, dials, sliders, etc.) that may be utilized to select and/or input various parameters, including a mode of operation, of system **1400**. Base unit **1452** may further include a USB and/or SD card slot for transferring data onsite without the use of a laptop or PC.

In another embodiment, some of the functionality of a base unit may be provided at a conventional building control panel, as described above in connection with FIGS. **12**-**13**D. For example, display screens and various user-activated mechanisms of a building control panel may be shared and utilized by system **1400**. In addition, such a building control panel may relay and distribute control signals from communication module **1412** of system **1400** to various devices under its control.

After installation of base unit **1452** and monitoring devices **1450**, any related software may be loaded onto a laptop, or use of a full-featured website may allow the user to configure reporting intervals and determine thresholds, and/or set readings desired for remote viewing. Configuration may be done onsite or remotely and settings may be changed at any time from the website interface, as would be understood by one skilled in the art. Networked system **1400** may be secured with login credentials, such as a user identification and password permitting access to only certain persons. Real time data may be automatically downloaded and stored to a server for future viewing. Networked system **1400** may provide for full access to system configuration settings, customizable thresholds and alarms, user access management (e.g., add, remove, and/or modify personnel access), and alerts the user or operator via cell phone, text message, email, etc., as would be understood by one skilled in the art.

Networked system **1400** may include an Internet connection adapted to transmit data from base unit **1452** (e.g., communication module **1412**) in real-time via the Internet to a website for monitoring, analysis, and downloading. This may be achieved by a LAN/WAN, or may require an internal wireless telecommunication system, such as a cellular-based (e.g., 3G or 4G) wireless connection for continuous data transmission. In one embodiment, thermal images and data may be collected locally via processor **1404** and then sent to a hosted website over an external network **1470** (e.g., the Internet) via a gateway **1472** (e.g., a wired or wireless router and/or modem) for remote viewing, control, and/or analysis. As such, networked system **1400** may utilize networkenabled, multi-point monitoring technology to collect a breadth of quality thermal images and data for monitoring and protection of various types of structures in a scalable manner.

Referring now to FIG. **15**, a flowchart is illustrated of a process **1500** for monitoring and controlling to enhance occupant safety and energy efficiency, in accordance with an embodiment of the disclosure. For purposes of describing process **1500**, references may be made to systems **1200**, **1300**A, **1300**B, and/or **1400** of FIGS. **12-14**, merely as an example of systems and components that may perform process **1500**. It should be appreciated that any other suitable systems and components may perform all or part of process **1500**.

At block **1502**, one or more thermal images of scene **1230** may be captured by one or more infrared imaging modules **1202/1302**. The one or more thermal images may be received, for example, at processor **1204/1304/1404** that is communicatively coupled via wired or wireless link to one or more infrared imaging modules **1202/1302**. In some embodiments, the captured thermal images optionally may be stored in memory (e.g., memory **1206/1306**) at block **1504**. At block **1506**, a NUC process may be performed to remove noise from the thermal images, for example, by using various NUC techniques disclosed herein.

For one or more embodiments, a mode of operation may be determined at block **1508**, and the one or more captured thermal images may be processed according to the determined mode of operation at block **1510**. In one embodiment, the mode of operation may be determined before or after the thermal images are captured and/or preprocessed (blocks **1502** and/or **1506**), depending upon the types of infrared detector settings (e.g., biasing, frame rate, signal levels, etc.), processing algorithms and techniques, and related configurations.

In one embodiment, for example, the mode of operation may be defined by mode sensing module **1216/1316**, wherein an application sensing portion of mode sensing module **1216/1316** may be adapted to automatically sense the mode of operation, and depending on the sensed application, mode sensing module **1216/1316** may be adapted to provide related data and/or information to processor **1204/1304/1404**. In another embodiment, the mode of operation may be manually set by a user via display **1208/1308/1408** and/or control module **1210/1310/1410** without departing from the scope of the present disclosure. In yet another embodiment, the mode of operation may be set automatically by processor **1204/1304/1404** if certain conditions are detected by various monitoring operations further described herein. For example, if fire, smoke, flood, or other hazardous condition is detected by system **1200/1300**A/**1300**B/**1400** operating in a hazardous condition detection mode, the mode of operation may be automatically switched to a rescue assistance mode to generate and provide information indicating where people are in a premise and whether they may need assistance.

In various embodiments, the modes of operation refer to processing of thermal images, and in response to the processed images, controlling operation of one or more devices, generating reports, issuing warnings, and/or displaying of infrared images. In some embodiments, thermal image processing algorithms are utilized to process an image under a variety of conditions, and the thermal image processing algorithms provide the user with one or more options to tune parameters and operate a monitoring and controlling system (e.g., system **1200/1300**A/**1300**B/**1400**) in an automatic mode or a manual mode. In various embodiments, the modes of operation are provided by the monitoring and controlling system, and thermal image processing for different use conditions may be implemented in various types of structure applications and resulting use conditions. In various embodiments, the modes of operation may include a power usage monitoring and control mode of operation, a hazardous condition monitoring mode of operation, an energy efficiency monitoring mode of operation, a rescue assistance mode of operation, and an intruder detection mode of operation. The monitoring and controlling system may be configured to simultaneously operate in any desired combination of such modes.

After processing the one or more thermal images according to the determined mode of operation, at block **1512** the one or more processed images and accompanying data may optionally be stored, and at block **1514**, may optionally be displayed. Additionally, in response to the results of processing in block **1510**, commands for actions to be taken, such as changing power or operation of one or more devices, instituting corrective action to mitigate hazardous conditions, generating alerts, and issuing reports, etc., may be generated at block **1516**. The generated command or control signals may then be transmitted to one or more devices to be controlled. For example, as described above in connection with FIGS. **12-14**, the control signals may be transmitted from communication module **1212/1312/1412**, directly to the one or more devices via wired/wireless link, or to a conventional building control panel that relays and/or distributes the control signals to devices under its control.

FIG. **16** illustrates a flowchart of a process **1600** for monitoring and controlling power usage in an area, in accordance with an embodiment of the disclosure. For example, process **1600** may be performed as part of process **1500** of FIG. **15**, such as at block **1510** (process thermal images according to mode of operation) and block **1516** (generate command for action).

At block **1602**, the captured thermal images, including data and information thereof, may be normalized, for example, to an absolute temperature scale by a radiometric normalization (e.g., performed by a submodule **1205** utilized by processor **1204** of system **1200**). At block **1604**, an emission spectrum analysis may be performed on the normalized radiometric images to detect for the presence of objects such as heat source, natural gas, other gas chemicals, etc., or to monitor environmental conditions such as temperature, humidity, etc.

In one embodiment, the emission spectrum analysis (e.g., thermal image data analysis) may be performed by analyzing the image data (e.g., radiometric image data) for intensity pattern in the near, middle, and far infrared spectrum. Objects of different composition and in different state (e.g., temperature) exhibit characteristic infrared spectral and intensity pattern. By correlating the spectral content and intensity profile of the radiometric image with the characteristic patterns emitted by different objects in different states, monitoring and controlling system (e.g., system **1200/1300**A/**1300**B/**1400**) may identify the objects and the state of the objects. For example, the emission spectrum analysis may identify that there are one or more persons in the room by detecting the spectral intensity pattern corresponding to the body temperature profile of a human. In another example, the emission spectrum analysis may identify that there is a powered-on laptop computer or determine the temperature in the room by detecting the signature spectral intensity pattern corresponding to the heat generated by a laptop computer or the spectral intensity pattern corresponding to the infrared radiation emitted by ambient air at a known temperature. The emission spectrum analysis may be performed using techniques disclosed herein and/or with video analytic software, as would be understood by one skilled in the art.

Further, in one aspect, by collecting scene statistics for each pixel location, a background model of the scene (e.g., scene **1230**) may be constructed. The exemplary background model may utilize an average of a time series of values for a given pixel. Because of the lack of shadows and general insensitivity to changing lighting conditions, background modeling may be more effective and less prone to false alarms with thermal images than visible light images. Once a background model has been constructed, regions of the images that differ from the background model may be identified. In the instance of a time series average as a background model, the background may be subtracted from the current captured video frame, and the difference may be compared to a threshold to find one or more "regions of interest" (ROI) corresponding to areas of greatest change. In one example, a detected ROI may indicate the presence of a person.

At block **1606**, based on the results of the emission spectrum analysis, determination may be made (e.g., by processor **1204/1304/1404**) whether there is a person within the FOV. If a person is detected, a command may be generated (e.g., by processor **1204/1304/1404**) and transmitted (e.g., via communication module **1212/1312/1412**) to appropriate devices and equipment to control the lighting in the room, at block **1608**.

For example, the emission spectrum analysis may detect the presence of a person when the person walks into a room. Processor **1204/1304/1404** may also determine from the emission spectrum analysis that a fluorescent light in the room is off because there is no detection of spectral intensity pattern corresponding to a powered-on fluorescent light. If the fluorescent light is connected to a network, processor **1204/1304/1404** may generate a power-on command to turn on the fluorescent light through the network. Thus, the infrared imaging system may act as an automatic light switch that turns on the light in a room when it detects the presence of a person in the room.

At block **1610**, environmental conditions, such as the temperature and/or humidity of an area, may be monitored and determined. For example, the emission spectrum analysis may analyze the thermal radiation level of ambient air outside of the proximity of objects that have been identified as heat source, such as a person or a fluorescent light, to determine the room temperature. In addition, the emission spectrum analysis may analyze the moisture level in the ambient air to determine the room humidity. In some embodiments, additional sensors such as temperature sensors and humidity sensors may be utilized for monitoring and determination of environmental conditions. At block **1612**, the emission spectrum analysis determines the number of persons by identifying the number of spectral intensity patterns corresponding to the body temperature profile of a human. Based on the detected room temperature, humidity, and/or the number of people in the room, a command may be generated to control the HVAC system to control the temperature and/or the air flow in the room, at block **1614**.

For example, if the HVAC system is connected to the network and the detected room temperature is higher than a desired temperature as determined by processor **1204/1304/1404**, a powered-on command and the desired temperature setting may be communicated to the HVAC system via communication module **1212/1312/1412**. Similarly, based on the number of persons in the room, processor **1204/1304/1404** may command the HVAC system to turn on the vent even if the temperature is at the desired temperature. Thus, the monitoring and controlling system (e.g., system **1200/1300**A/**1300**B/**1400**) may act as an automatic thermostat that controls the HVAC system as a function of the number of persons in the room.

Turning now to the case in which no person was detected, if the emission spectrum analysis revealed that the light in the room is on, a command may be generated and transmitted to the lighting system to turn off the lights in the room, at block **1616**. The emission spectrum analysis may similarly allow detection and control of power usage of computers and other appliances. For example, at block **1618**, the emission spectrum analysis determines if a computer or an appliance is powered on by analyzing the thermal radiation level to detect the spectral intensity pattern corresponding to heat generated from a computer, an appliance, or other types of power-consuming devices. Once a powered-on device is detected, the emission spectrum analysis further determines the type of device by correlating the spectral intensity pattern against the characteristic pattern radiated by various types of devices, at block **1620**. The length of time a device is powered on may also be determined. At block **1622**, appropriate commands may be generated to control the power to a device based on the type of device and the length of time the device is powered on.

For example, blocks **1618** and **1620** may determine that a gas range is burning gas in one of the burners without the presence of a person in the room. Processor **1204/1304/1404** may set a time limit that the gas range is allowed to burn unattended. Then, at block **1622**, if the time limit is reached, processor **1204/1304/1404** may, through the network, command the gas range to turn off gas to the burner so as to reduce the risk of fire hazard. In another example, blocks **1618** and **1620** may determine that a television set in the room is powered on without the presence of a person. Again, processor **1204/1304/1404** may set a time limit that the television set is allowed to be on with no one watching. In step **423**, if the time limit is reached, processor **1204/1304/1404** may, through the network, command the television set to turn off so as to conserve power. Thus, the infrared imaging system may automatically control power to unattended appliances or devices for safety and conservation considerations.

In another embodiment, if there is no person in the area, the monitoring and controlling system may lower the temperature setting on the hot water heater in the house to conserve energy. In another embodiment, if there is no person in the house for an extended period of time, the monitoring and controlling system may command the hot water heater to go into the vacation mode. Conversely, the monitoring and controlling system may command the hot water heater to exist the vacation mode when it detects a person in the house or it may adjust the water temperature setting as a function of the number of persons detected in a house. It is also contemplated that process **1600** may be used to detect water in the environment through the emission spectrum analysis, such as determining that it is raining so that the infrared imaging system may shut off the sprinkler system for water conservation.

FIG. **17** illustrates a flowchart of a process **1700** for detecting hazardous conditions in an area, in accordance with an embodiment of the disclosure. As with process **1600**, process **1700** may be performed as part of process **1500** of FIG. **15**, such as at block **1510** (process thermal images according to mode of operation) and block **1516** (generate command for action).

At block **1702**, the captured thermal images are normalized by a radiometric normalization process. Block **1702** may be similar to block **1602** of FIG. **16**. At block **1704**, an emission spectrum analysis may be performed on the radiometric images to detect for the presence of hazardous chemicals or conditions such as a natural gas leak, carbon monoxide, volatile organic compound, fire, smoke, etc. As in block **1604**, the emission spectrum analysis may be performed for different regions of the infrared spectrum. The spectral intensity pattern of the radiometric image may be correlated against the characteristic patterns emitted by different chemicals in different states to identify the presence of the chemicals and the state they are in.

At block **1706**, based on the results of the emission spectrum analysis, determination may be made (e.g., by processor **1204**/**1304**/**1404**) whether hazardous or combustible gas is present in the area. For example, the emission spectrum analysis may correlate the spectral intensity pattern of the captured image against the pattern corresponding to combustible hydrocarbon gas (e.g., methane/natural gas, propane, butane, pentane), volatile organic compound (e.g., benzene, toluene, various ethers, various ketones), carbon monoxide, or other types of gas detectible using infrared emission spectrum analysis. If there is sufficient correlation, processing component may determine that hazardous or combustible gas is present.

At block **1708**, the emission spectrum analysis further analyzes the profile of the gas to determine the source of the gas and to further identify the safety hazard. For example, it may be determined from the spectral intensity pattern that there is a plume of natural gas in the room leaking from a gas pipe. Alternatively, it may be determined that the natural gas is merely residual gas that was not burned off completely from combustion in the burner of a gas range.

If it is determined that there is a hazardous gas leak, a command may be generated to turn off the gas at the source, at block **1710**. For example, if a gas pipe is leaking natural gas and a gas valve controlling an inflow of gas is controllable from the network, processor **1204**/**1304**/**1404** may generate a command to the gas valve to shut off the flow of gas to prevent further build up of natural gas in the room. In another example, if carbon monoxide (CO) is detected as coming from a gas heater in an unventilated room, processor **1204**/**1304**/**1404** may generate a command to turn off the gas heater if it is controllable from the network. Alternatively or additionally, processor **1204**/**1304**/**1404** may generate a warning or sound an alarm to warn occupants in the room of the hazard.

At block **1712**, the emission spectrum analysis may be further utilized to detect fire or smoke that may be the source of the gas. For example, the emission spectrum analysis analyzes the spectral intensity pattern for patterns corresponding to fire or smoke. If fire or smoke is detected, an alarm may be triggered at block **1714**. An alarm may also be triggered if the source of the gas can not be controlled to shut off the gas, if the source of the gas can not be identified, or in other situations where it is prudent to evacuate the room. If fire or smoke is not detected and evacuation is not necessary, a warning or a report of the result may be generated, such as to display **1208**/**1308**/**1408**. Thus, the monitoring and controlling system (e.g., system **1200**/**1300**A/**1300**B/**1400**) may act as a carbon monoxide detector, a natural gas detector, a fire/smoke alarm, or as a detector for other types of hazardous or combustible gas.

Turning now to the case in which no hazardous or combustible gas was detected, the emission spectrum may be further utilized to detect electrical hot spots or other types of safety hazards. For example, at block **1718**, the emission spectrum analysis searches for electrical hot spots by analyzing the thermal radiation level for pattern that corresponds to heat generated from electrical hot spots.

If an electrical hot spot is detected, the emission spectrum analysis further analyzes, at block **1720**, the profile of the hot spot to determine whether it is an electrical short or other types of electrical hazards. It will be appreciated that the emission spectrum analysis may detect electrical hot spots and hazards from various sources including, but not limited to, various types of electrical devices, appliances, and equipment (e.g., fuse, circuit breaker, electrical outlet, power generator, power distribution board, etc.). For example, a profile of the hot spot may indicate that the electrical hot spot is from a coffee maker. From the profile of the heat or the spectral intensity pattern of water vapor evaporating from the coffee maker, the emission spectrum analysis may further determine whether there is water in the coffee pot. Alternatively, a profile of the hot spot may indicate that it is caused by an electrical short in an appliance.

At block **1722**, from the results of emission spectrum analysis, appropriate commands may be generated to control power to the appliances if there is a safety hazard. For example, if a coffee maker is turned on without water in the coffee pot, processor **1204**/**1304**/**1404** may, through the network, command the coffee maker to turn off. Thus, the monitoring and controlling system (e.g., system **1200**/**1300**A/**1300**B/**1400**) may act as a detector of electrical hazards and further controls power to electrical devices to remedy the electrical hazards. If the electrical hot spot can not be remedied by powering off the appliance, such as an electrical short in a wall circuit or in an extension cord, processor **1204**/**1304**/**1404** may turn off power to the circuit at block **1724**. In this manner, the monitoring and controlling system may act as a circuit breaker.

In addition to being used as a detector of safety hazards, the monitoring and controlling system may further perform, at block **1726**, thermo-mechanical analysis of appliances to prevent the safety hazards from developing in the first place. For example, for a water heater that undergoes repeated heating/cooling cycles, the emission spectrum analysis may track the number of heating cycles and the history of the water temperature to warn when the water heater needs to be replaced due to thermal metal fatigue. In addition to detecting electrical hot spots and other safety hazards, it is contemplated that process **1700** may be used to detect wet spot, water leak, ruptured plumbing, or water damage that may result from plumbing problems or leaky roofs. Thus, the monitoring and controlling system may act as a detector of water problem in the house.

FIG. **18** illustrates a flowchart of a process **1800** for monitoring and analyzing energy usage and environmental condition for maximizing energy efficiency in a structure, in accordance with an embodiment of the disclosure. As with processes **1600** and **1700**, process **1800** may be performed as part of process **1500** of FIG. **15**, such as at block **1510** (process thermal images according to mode of operation) and block **1516** (generate command for action).

At block **1802**, the captured thermal images are normalized by a radiometric normalization process. Block **1802** may be similar to block **1602** of FIG. **16**. At block **1804**, an emission spectrum analysis may be performed on the radiometric images to analyze how energy is used. For example, the emission spectrum analysis may analyze the thermal radiation level to detect heat generated from power-consuming devices. The type of device may be determined by correlating the spectral intensity pattern against the characteristic pattern radiated by various types of devices. Processor **1204/1304/1404** may track the time the devices are in operation. From the knowledge of the types of device and their time of operation, processor **1204/1304/1404** may generate an audit report of energy usage in the room. Reports from multiple rooms may be combined to generate an energy audit report for the house or building. As a result, the energy audit report may show the energy usage for computers, household appliances, lighting, and HVAC system in the house over time.

At block **1806**, environmental conditions such as temperature, humidity, etc. may be monitored at various points in a structure. In one embodiment, the emission spectrum analysis may analyze the thermal radiation level to monitor the distribution of thermal energy in a room. For example, if there is insufficient thermal insulation around windows or doors, the air temperature around the poorly insulated windows or doors may be cooler relative to the rest of the room when air temperature inside the room is warmer than outside air temperature. Conversely, the air temperature around the windows or doors may be warmer relative to the rest of the room when inside temperature is cooler than outside temperature. Thus, the monitoring and controlling system (e.g., system **1200**/**1300**A/**1300**B/**1400**) may monitor environmental conditions to determine the energy efficiency of the room.

From knowledge of energy use and energy efficiency, appropriate commands may be generated, at block **1808**, to control power usage in the room or in the structure to maximize energy efficiency. For example, processor **1204/1304/1404** may control the HVAC system to reduce energy usage when the occupants of the house are asleep such as by redistributing heating/cooling to bedrooms or by adjusting the temperature setting in the house. In one embodiment, appropriate commands may be generated to control the shade, blind, or fan in the room to reduce heat loss or to dissipate excess heat from the room. In another embodiment, the monitoring and controlling system may be integrated with the smart grid system to schedule power usage in the structure so as to minimize energy cost and to reduce energy use during time of peak demand. For example, processor **1204/1304/1404** may schedule appliances such as the dishwasher, washing machine, and/or dryer to run at night to take advantage of the lower billing rate for energy usage during time of less demand.

At block **1810**, a report of energy use for the house or building over time may be generated from results of the emission spectrum analysis. The report may identify areas of energy inefficiency and may recommend ways to remedy the problem. For example, for a poorly insulated house or building, the report may suggest areas needing enhanced insulation. Thus, the monitoring and controlling system (e.g., system **1200**/**1300**A/**1300**B/**1400**) may act as an energy monitoring system that automatically controls power usage and generates audit report to maximize energy efficiency and minimize energy cost for a house or a building.

FIG. **19** illustrates a flowchart of a process **1900** for monitoring and reporting persons in need of assistance, in accordance with an embodiment of the disclosure. For example, process **1900** may be performed as part of process **1500** of FIG. **15**, such as at block **1510** (process thermal images according to mode of operation) and block **1516** (generate command for action), when an emergency is detected.

At block **1902**, the captured thermal images are normalized by a radiometric normalization process. Block **1902** may be similar to block **1602** of FIG. **16**. At block **1904**, an emission spectrum analysis may be performed. Based on the emission spectrum analysis, a determination may be made (e.g., by processor **1204/1304/1404**) whether there is a person within the field of view, at block **1906**. Blocks **1904** and **1906** may be similar to blocks **1604** and **1606** of FIG. **16**, respectively.

If one or more persons are detected, various attributes of the detected persons may be determined based on further analysis of the radiometric thermal images, at block **1908**. In one embodiment, a posture of the detected person may be determined by analyzing the profile and aspect ratio of the detected person in the thermal images. For example, whether a person is standing up or has fallen down may be determined by techniques described in commonly assigned PCT Patent Application PCT/US2-12/025692 filed Feb. 17, 2012, which claims priority to U.S. Provisional Patent Application No. 61/445,254 filed Feb. 22, 2011, which are incorporated herein by reference in their entirety. Other attributes, such as the approximate body temperature of the detected person and the duration for which the person remained motionless, may also be determined. Alternatively or in addition, various thermal image software analysis tools (e.g., video analytics) may be applied for thermal image analysis in accordance with the techniques disclosed herein and as would be understood by one skilled in the art.

At block **1910**, based on the attributes, a determination may be made as to whether the detected person may be in need of assistance. For example, it may be determined whether a person has been lying down motionless for more than a certain length of time and/or has a body temperature below a normal range. If so, the detected person may be marked as likely to need assistance.

At block **1912**, information regarding the detected person may be transmitted to and/or accessed at a central reporting system (e.g., via communication module **1212** or base unit **1452**). Such information may include the location of the detected person, the attributes of the detected persons, and whether the person likely needs assistance. Thus, for example, process **1900** may provide to emergency responders beneficial information that may be utilized to locate rescuees and plan a rescue operation (e.g., prioritize rescuees based on the indication of whether they may need assistance).

FIG. **20** illustrates a flowchart of a process **2000** for detecting intruders, in accordance with an embodiment of the disclosure. For example, process **2000** may be performed as part of process **1500** of FIG. **15**, such as at block **1510** (process thermal images according to mode of operation) and block **1516** (generate command for action).

At block **2002**, the captured thermal images are normalized by a radiometric normalization process. Block **2002** may be similar to block **1602** of FIG. **16**. At block **2004**, an emission spectrum analysis may be performed. Based on the emission spectrum analysis, a determination may be made (e.g., by processor **1204/1304/1404**) whether there is a person within the field of view, at block **2006**. Blocks **2004** and **2006** may be similar to blocks **1604** and **1606** of FIG. **16**, respectively.

If a person is detected in the thermal images based on the emission spectrum analysis, an alarm may be generated (e.g., activating alarms **1458**, an email alert, a text message, and/or any other desired form of communication for a desired warning) at block **2008** to notify appropriate people (e.g., home owner, the police, or other appropriate personnel). Because the various radiometric thermal image analyses as described above may be utilized to detect of a presence of a person (e.g., an intruder, a burglar, or other unwanted persons), process **2000** may be much less prone to false detection. For example, whereas conventional security sensor systems may be falsely triggered by pets and animals left in premises, thermal image analyses may permit differentiating between persons and animals and thus provide more robust and accurate security monitoring.

In general in accordance with one or more embodiments, thermal sensors may be strategically positioned in a building for use to monitor and control various building parameters (e.g., HVAC system, environmental conditions, building equipment, hazard detection, safety and rescue, and/or emergency sensors, etc., as disclosed herein) and provide an alert/document and/or allow first responders to access a central reporting system (e.g., processor or control system) to view information and respond accordingly. As an example for some embodiments, the number, physical (e.g., health) status, and location of people remaining in the building may be determined based on the thermal sensor information, which may allow responders (e.g., building management and/or emergency personnel) to prioritize their actions (e.g., persons lying on the ground or trapped in a dangerous location may be given higher priority).

As a further example for some embodiments, the thermal sensor information may also be used as security sensors for alarm systems (e.g., intruder alert). The thermal sensor information may also be analyzed to differentiate between humans and animals, which may reduce false alarm rates (e.g., in homes with pets). The thermal sensor information may be analyzed, as discussed herein and/or based on video analytic software, to compile the indicated information and analyze the thermal image data, as would be understood by one skilled in the art.

Where applicable, various embodiments provided by the present disclosure can be implemented using hardware, software, or combinations of hardware and software. Also where applicable, the various hardware components and/or software components set forth herein can be combined into composite components comprising software, hardware, and/or both without departing from the spirit of the present disclosure. Where applicable, the various hardware components and/or software components set forth herein can be separated into sub-components comprising software, hardware, or both without departing from the spirit of the present disclosure. In addition, where applicable, it is contemplated that software components can be implemented as hardware components, and vice-versa.

Software in accordance with the present disclosure, such as non-transitory instructions, program code, and/or data, can be stored on one or more non-transitory machine readable mediums. It is also contemplated that software identified herein can be implemented using one or more general purpose or specific purpose computers and/or computer systems, networked and/or otherwise. Where applicable, the ordering of various steps described herein can be changed, combined into composite steps, and/or separated into sub-steps to provide features described herein.

Embodiments described above illustrate but do not limit the invention. It should also be understood that numerous modifications and variations are possible in accordance with the principles of the invention. Accordingly, the scope of the invention is defined only by the following claims.

What is claimed is:

1. A system comprising:

one or more infrared imaging modules comprising a focal plane array (FPA) configured to:

capture thermal images of an area, and

capture a thermal image frame that comprises thermal image data and noise introduced by the infrared imaging module;

a processor configured to:

determine, for each row of the thermal image frame, a corresponding row fixed-pattern noise (FPN) correction term, and for each column of the thermal image frame, a corresponding column FPN correction term;

apply the row and the column FPN correction terms to the thermal image frame to provide a corrected thermal image frame;

process the corrected image frame to determine a plurality of non-uniform correction (NUC) terms to reduce a portion of the noise comprising spatially uncorrelated FPN,

apply the NUC terms to the thermal images,

perform an analysis of the thermal images,

determine a presence of one or more persons present in the area based on the analysis of the thermal images,

identify one or more objects in the area,

determine respective power usage states associated with the one or more objects in the area based on the analysis of the thermal images, and

generate control signals to control future power usage associated with the one or more objects in response to the presence of one or more persons present in the area and the determined power usage states respectively associated with the one or more objects; and

a network interface component (NIC) configured to transmit the control signals to control the future power usage of the one or more objects.

2. The system of claim **1**, wherein:

the one or more objects include at least one of a heater, an air conditioner, a heating ventilation air conditioning (HVAC) unit, a water heater, an oven, a lamp, or a lighting fixture; and

the one or more infrared imaging modules are radiometrically calibrated to generate the thermal images that is radiometrically normalized to a temperature scale.

3. The system of claim **1**, wherein the processor is further configured to:

identify a hazardous condition in the area and to determine a source of the hazardous condition based on the analysis of the thermal images;

generate a control signal to remedy the hazardous condition if the source is controllable; and

generate a warning if the hazardous condition is not capable of being remedied.

4. The system of claim **3**, wherein the identified hazardous condition includes at least one of a carbon monoxide (CO) gas leak, a combustible gas leak, fire, smoke, an electrical hot spot, a water leak, or flood.

5. The system of claim **1**, wherein the processor is further configured to:

determine one or more environmental conditions including a humidity level of the area; and

generate the control signals in further response to the one or more determined environmental conditions of the area.

6. The system of claim **1**, wherein the processor is further configured to identify respective object types of the one or more objects based on the analysis of the thermal images, and to generate the control signals in further response to the respective object types of the one or more objects.

7. The system of claim 1, wherein the processor is further configured determine energy usage associated with the one or more objects.

8. The system of claim 7, wherein the processor is further configured to:

perform an analysis of the energy usage associated with the one or more objects; and

make suggestions to increase energy efficiency of the one or more objects.

9. The system of claim 1, wherein:

the thermal images are unblurred thermal images of the area; and

the thermal image frame comprises an intentionally blurred thermal image frame that comprises thermal image data associated with the area and the noise introduced by the infrared imaging module.

10. A method comprising:

capturing, at a focal plane array of an infrared imaging module, thermal images of an area;

capturing a thermal image frame that comprises thermal image data and noise introduced by the infrared imaging module;

determining, for each row of the thermal image frame, a corresponding row fixed-pattern noise (FPN) correction term, and for each column of the thermal image frame, a corresponding column FPN correction term;

applying the row and the column FPN correction terms to the thermal image frame to provide a corrected thermal image frame;

processing the corrected image frame to determine a plurality of non-uniform correction (NUC) terms to reduce a portion of the noise comprising spatially uncorrelated FPN,

applying the NUC terms to the thermal images;

performing an analysis of the thermal images;

determining a presence of one or more persons present in the area based on the analysis of the thermal images;

identifying one or more objects in the area;

determining respective power usage states associated with the one or more objects in the area based on the analysis of the thermal images;

generating control signals to control future power usage associated with the one or more objects in response to the presence of one or more persons present in the area and the determined power usage states respectively with the one or more objects; and

communicating the control signals to the one or more objects over a network.

11. The method of claim 10, further comprising radiometrically normalizing the thermal images to a temperature scale, wherein the one or more objects include at least one of a heater, an air conditioner, a heating ventilation air conditioning (HVAC) unit, a water heater, an oven, a lamp, or a lighting fixture.

12. The method of claim 10, wherein:

identifying a hazardous condition in the area and determining a source of the hazardous condition based on the analysis of the thermal images; and

said generating of the control signals comprises:

generating a control signal to the source to remedy the hazardous condition if the source is controllable; and

generating a warning if the hazardous condition is not capable of being remedied.

13. The method of claim 12, wherein the identified hazardous condition includes at least one of a carbon monoxide (CO) gas leak, a combustible gas leak, fire, smoke, an electrical hot spot, a water leak, or flood.

14. The method of claim 10, wherein:

determining one or more environmental conditions including a humidity level of the area; and

said generating of the control signals is in further response to the one or more determined environmental conditions of the area.

15. The method of claim 10, wherein:

the method further comprises identifying respective object types of the one or more objects based on the analysis of the thermal images; and

said generating of the control signals is in further response to the respective object types of the one or more object types.

16. The method of claim 10, further comprising determining energy usage associated with the one or more objects.

17. The method of claim 16, further comprising:

performing an analysis of the energy usage associated with the one or more objects; and

making suggestions to increase energy efficiency of the one or more objects.

18. The method of claim 10, wherein:

the thermal images are unblurred thermal images; and

the thermal image frame comprises an intentionally blurred thermal image frame that comprises thermal image data associated with the external environment and the noise introduced by the infrared imaging module.

19. The system of claim 1, wherein the processor is further configured to:

determine a number and physical statuses of persons present in the area based on the analysis of the thermal images, the physical statuses including postures and/or durations of motionlessness of persons present in the area determined based on the analysis of the thermal images;

determine that the persons present in the area are asleep or resting based on the postures and/or the duration of motionlessness of the persons; and

generate control signals to reduce the future power usage associated with the one or more objects in response to determining that the persons present in the area are asleep or resting.

20. The method of claim 10, further comprising:

determining a number and physical statuses of persons present in the area based on the analysis of the thermal images, the physical statuses including postures and/or durations of motionlessness of persons present in the area determined based on the analysis of the thermal images;

determining that the persons present in the area are asleep or resting based on the postures and/or the duration of motionlessness of the persons; and

generating control signals to reduce the future power usage associated with the one or more objects in response to determining that the persons present in the area are asleep or resting.

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